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IMPROVED COUPLING OF THE CONDUCTION AND FLOW EQUATIONS IN TRAC*

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Recent nuclear-reactor-systems modeling efforts have been directed toward the development of computer codes capable of simulating transients in short computational times. For this reason, a stability enhancing two-step method (SETS)[1] has been applied to the two-phase flow equations in the Transient Reactor Analysis Code (TRAC)[2] allowing the Courant limit to be violated. Unfortunately, the coupling between the wall conduction equation and the fluid-dynamics equations is performed semi-implicitly that is, the wall-heat transfer term,

$$q = h^n \left(T_w^n - T_c^{n+1}\right) \quad , \tag{1}$$

is evaluated using old-time heat-transfer coefficients (h) and wall temperatures (T_w) and new-time coolant temperatures (T_c). This coupling may lead to numerical instabilities at large time steps because of large variations in the heat-transfer coefficient in certain regimes of the boiling curve. Consequently, simply using new-time wall temperatures in Eq. (1) is not sufficient. A technique that also incorporates new-time heat-transfer coefficients must be used.

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An example of large variations of the heat-transfer coefficient for small changes in the void fraction (α) is illustrated in Fig. 1. This regime typically is encountered on the secondary side of a steam generator. Computations in this heat-transfer regime for a once-through steam-generator model result in the temporal trace provided in Fig. 2a for large time steps (maximum Δt = 2 s). As steady state is approached, large numerical oscillations in the fluid properties occur in the fluid cell with a void fraction of 0.979. Ultimately, the computation fails.

One technique that has proven successful in circumventing this dilemma without reducing the time-step size is to average old- and new-time heat-transfer coefficients. Both logarithmic and arithmetic averaging have been used. Unfortunately, an unacceptably large weighting of the older value is required. The result of using a logarithmic average and weighting the older value by 90% is shown in Fig. 2b for a maximum Δt of 2 s .

Methods that more implicitly couple the equations recently have been implemented in the TRAC code. They offer the advantage of eliminating the need to increase the size of the matrices required for a new time solution. Consider the linearized form of Eq. (1),

$$q^{k+1} = h^k (T_w^k - T_c^k) + h^k (\delta T_w - \delta T_c) + \Sigma_i \left(\frac{\partial h}{\partial x_i}\right)^k \delta x_i (T_w^k - T_c^k) , \quad (2)$$

where k indicates the k^{th} iteration for the $n+1$ time step, x_i are the independent variables, and $\delta x_i = x_i^{k+1} - x_i^k$. In the initial technique that was investigated, the derivatives of the heat-transfer coefficients were evaluated at the beginning of each time step. This method resulted in only limited success. Checking the change in the wall temperature after a time step and repeating the step with updated

derivatives for large relative changes in T_w also did not provide the necessary stability. A stable solution results only when the derivatives ($\partial h/\partial x$) are updated iteratively internal to the fluid-dynamics solution technique (refer to Fig. 2c).

Preliminary comparisons between the original semi-implicit, the logarithmic-averaging, and the implicit techniques are provided in Table I. The time step had to be smaller than 0.7 s to obtain a stable solution for the original method. As already mentioned, the logarithmic-averaging technique used a heavily weighted older value.

At first glance, the original technique using smaller time steps appears substantially faster than the implicit technique, which requires additional computation to evaluate the heat-transfer coefficients and their derivatives for each time step. The 8-s difference in computation times between the semi-implicit and implicit techniques occurs in the first 60 s of calculation time. This period is prior to the oscillatory numerical behavior encountered as steady state was approached in the semi-implicit run with a large maximum Δt (refer to Fig 2a). Presently, all derivatives are computed numerically. The implicit technique should be more competitive if only the largest derivatives (those with respect to void fraction and wall temperature) are retained and if an analytic method to evaluate these derivatives is available.

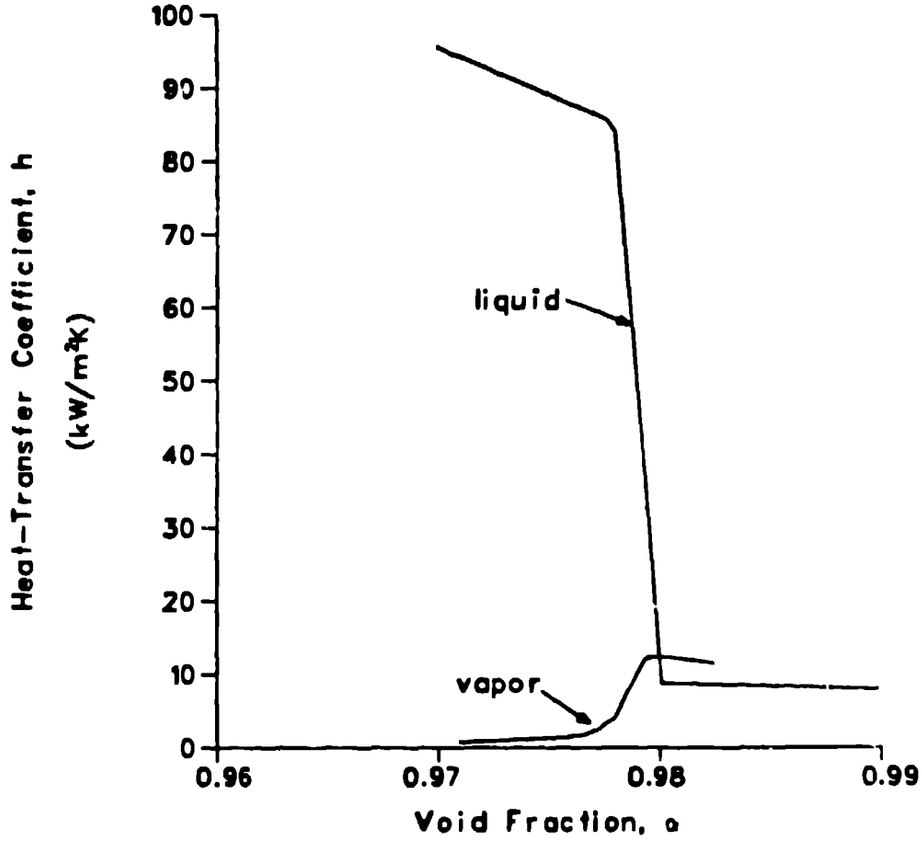

Fig. 1.

Heat-transfer coefficients for large void fraction.

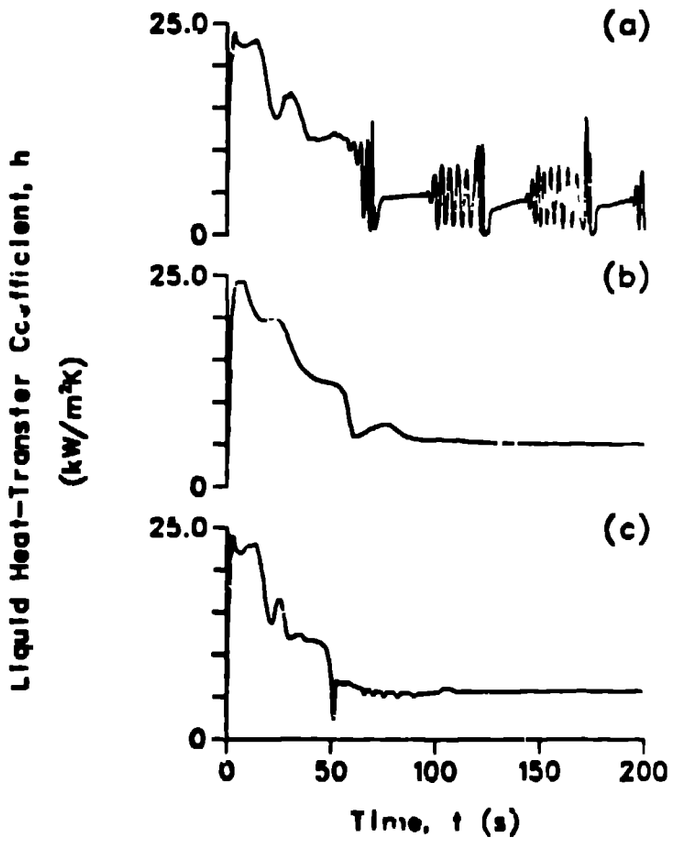

Fig. 2.

Temporal response of the liquid heat-transfer coefficient for a maximum Δt of 2 s:

(a) semi-implicit,
(b) logarithmic average, and
(c) implicit.

TABLE I

COMPARISON OF COUPLING TECHNIQUES

	Techniques		
	Semi-implicit	Log average	Implicit
Number of time steps	340	175	256
Time-step size, Δt (s)	0.7	2.0	2.0
CPU time (s)	12.33	7.15	19.87

REFERENCES

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2. "TRAC-PD2, An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Loss-of-Coolant Accident Analysis," Los Alamos National Laboratory report LA-8709-MS, NUREG/CR-2054 (April 1981).