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EDITORIAL NOTE

This volume contains the text of all papers together with a concentrated form of all discussions. Due to the time limitation it was not possible to present the proposed texts again to the authors before printing. Therefore it might be possible that some errors are contained in the written text, mainly in the discussions. The editor apologizes in advance for this and takes the sole responsibility.

The publication represents the joint effort of many people. Thanks are given to all involved with the organisation and performance of the meeting and in particular to Mrs J. Lott and Mrs L. Neumann for their help in the organisation of the meeting and the typing work.

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Welcome

O. Haxel

Geschäftsführer der Gesellschaft für Kernforschung mbH., Karlsruhe

Im Namen des Kernforschungszentrums Karlsruhe begrüße ich Sie herzlich zu der Internationalen Tagung über Reactor Heat Transfer. Ich danke den Kollegen die aus Übersee, aus Japan, U.S.A., Kanada, von den britischen Inseln, aus Rußland und den übrigen europäischen Ländern gekommen sind. Ferner gilt mein Dank auch der British Nuclear Energy Society und der Local Section in Central Europe der American Nuclear Society und der Kerntechnischen Gesellschaft im deutschen Atomforum dafür, daß sie diese Tagung hier in unserem Kernforschungszentrum Karlsruhe ausgerichtet haben und damit unseren Mitarbeitern die Möglichkeit geben den Vorträgen und Diskussionen so vieler Experten zu folgen.

Das Problem des Wärmeübergangs ist nicht neu, es ist so alt wie die gesamte Technik. Allerdings vor hundert Jahren waren die Randbedingungen etwas anders. Man mußte dafür sorgen, daß in einem Kessel die Flammengase sich entwickeln konnten. Die Korrosionsprobleme durch diese Flammengase standen im Vordergrund und man mußte dafür sorgen, daß Ruß und Asche den Kessel nicht verstopfen. Es bestand natürlich auch damals schon das Interesse möglichst viel der entstandenen Wärme auf das Arbeitsmittel, damals ausschließlich Wasser, zu übertragen.

In der nuklearen Technik haben wir saubere Verhältnisse. Es ist alles klar überschaubar und das Herz des Ingenieurwissenschaftlers muß sich darüber freuen. Trotz aller geleisteten Arbeit ist auch das Problem des Wärmeübergangs selbst in dem einfachen Fall der Einphasenströmung heute noch nicht vollkommen aufgeklärt. Viel weniger in dem sehr viel komplexeren Bereich der Zweiphasenströmung. Der Reaktoringenieur interessiert sich ja nicht nur für den Normalbetrieb, er möchte auch die Situation bei Kühlmittelblockaden und bei Brennelementdeformationen voll in den Griff, d.h. in den Griff seiner Rechencodes, bekommen. Auch die komplizierten Strömungsvorgänge bei Kühlmittelverlustunfällen mit anschließenden Fluten des Cores wollen überschaubar gestaltet werden. Ein weiteres Kapitel, ein nicht unwichtiges, sind die Strömungsinstabilitäten mit ihren Rückwirkungen auf den Wärmefluß. Sie rufen Schwingungen der Gas- und Flüssigkeitskörper hervor, Vibrationen der Bauelemente und führen zu unerwünschten mechanischen Belastungen, die ebenfalls mathematisch erfaßbar gemacht werden müssen. Eine Tagung wie diesesoll in erster Linie dem wisschenschaftlichen Austausch dienen, der ja uns allen zu Gute kommt und das Leben erleichtert und es uns erlaubt die Rohstoffe dieser Erde besser auszunutzen.

Ein solches internationales Treffen hat aber nebenbei noch eine andere Aufgabe. Es soll mit dazu helfen, das in anderen Lebensbereichen außerhalb der Wissenschaft bestehende Mißtrauen abzubauen, Mißverständnisse zu beseitigen und damit beizutragen, daß die Spannungen zwischen verschiedenen Ländern und Regionen abgebaut werden. Auf dem Hintergrund der schrecklichen Vorgänge im Nahen Osten, die uns alle bedrücken, gewinnt gerade diese Seite eines internationalen Treffens an Bedeutung. Wir alle wollen hoffen, daß in den vom Unheil betroffenen Ländern so rasch wie möglich der Geist des gegenseitigen Verstehens und der Versöhnung einzieht. So wünsche ich ihrer Tagung einen großen wisschenschaftlichen Erfolg und hoffe, daß auch Sie einen kleinen Beitrag zur internationalen Entspannung leisten.

S E S S I O N I

One Phase Flow, Mixing and Turbulence Promoters

Chairman: H.G. Lyall
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Paper No. 49

Experimental Mixing Studies in Simulated Wire-Wrap Fuel Assemblies

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1. Introduction

Lumped-parameter computer codes are widely used in engineering design and analysis of LMFBR fuel assemblies containing helical-wire spacer systems. Early versions of these codes employed "effective" turbulent mixing models to describe the apparently enhanced mixing action of helical-wire spacers. Much of the early experimental work directed towards development of these codes, therefore, involved deducing turbulent mixing coefficients for application to helical-wire systems. This work is reviewed in detail in [1].

In 1970, Marion and Hines [2] published results obtained from a tracer type mixing experiment which was carefully designed to reveal the influence of the mixing mechanism in helical-wire systems on the dispersion of the tracer. Results obtained by Skok [3] followed shortly thereafter. Both of these sets of data were interpreted to indicate that the interchannel mixing mechanism is (i) highly directional in nature and that (ii) the magnitude of the mixing rate varies strongly with axial distance [4]. Both of these conclusions, of course, contradict the use of turbulent mixing models.

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Several interchannel mixing models for helical-spacer systems have subsequently been proposed [5-8] which account for both the directional nature of the crossflow mechanism, and for the axial dependence of the mixing rate. Some of the models have been incorporated into lumped-parameter computer codes [6,9-12]. Two representative models, which are used for comparative purposes in this paper, are discussed in Section 2.

Based on the research cited above, and on experimental results obtained by Collingham, et al. [13] and Fontana, et al. [15], the following qualitative picture emerges of the mixing mechanism in fuel assemblies containing helical-wire spacer systems:

Interchannel mixing is characterized by a directed, convective component of flow induced by the spacer wires. For "interior" subchannels the component of flow between adjacent subchannels varies with axial distance in a periodic manner, with an average mixing rate over a length P_s of zero. For mixing between "peripheral" subchannels (those bordering the subassembly walls), the convective crossflow is also periodic, but with a non-zero average over a length P_s. Fluid is transported around the hexagonal walls of the fuel assembly in the direction of rotation of the spacer wires.

While the various codes agree reasonably well in their prediction of interior subchannel behavior, there is considerably less agreement both with comparative predictions of peripheral subchannel flow characteristics and with experimental data for these subchannels [15]. The problems here are:

(i) Techniques for direct measurement of the flow component around the hexagonal walls of fuel assemblies have not yet been developed. The flow component must be deduced from tracer-type mixing data in conjunction with a postulated model of the flow behavior by, essentially, trial and error methods.

(ii) Large tracer concentration gradients have been found to exist in peripheral subchannels, thus complicating interpretation of peripheral subchannel data [13].

(iii) Code computations indicate that the flow characteristics around the periphery of a fuel assembly depends strongly on the size (number of fuel elements) of the assembly.

If (iii) is true, then the implication is that one must obtain data from tests of full-scale fuel assemblies (217-pins). At the least, one must know how to extrapolate results from small-scale to large-scale assemblies. Even though extensive 217-pin experiments have been performed [13], the conclusions to be drawn from these results are complicated by problems associated with interpretation of peripheral subchannel data taken in the vicinity of large concentration gradients.

Thus, while a number of computer codes are available which incorporate "advanced" models of the convective crossflow mechanism characteristic of helical-wire spacer systems, the need exists for additional data for evaluation of the various models. Special emphasis is required on peripheral subchannel behavior. In addition, for effective use of the codes in engineering design and analysis, the empirical data required by the mixing models is required as a function of system parameters. The experiments must be carefully designed, however, to avoid the difficulties encountered in previous research efforts.

This paper presents the results of ANL-CTD efforts to develop an experimental procedure for acquisition of reliable mixing data in helical-wire spacer systems. The experimental procedure is described, and the results of tracer mixing studies using 7-pin triangular geometry are presented. The results are interpreted to give a reasonably complete description of the transport processes in a 7-pin test-section, and the data is compared with two of the available lumped-parameter computer codes, COBRA-IIIB [6] and SWEEP [9]. Finally, test plans for a 91-pin test series are discussed.

2. Forced Flow Mixing Models

The models cited above can be categorized as either "pulse" or "continuous" models. One representative model from each category is briefly discussed below in conjunction with the computer code in which the model is implemented. The two codes were used for comparison with experimental data.

2.1 A "Pulse" Model: COBRA-IIIB [6]

Rowe proposed that where a spacer wire crosses a gap between adjacent subchannels, the crossflow per unit length is

$$w_{ij} = \pi\left(\frac{D+t}{P_s}\right) \frac{s_{ij}}{A_i} W_i \qquad (1)$$

If Eq. (1) were applicable for all x, then the total crossflow in one spacer pitch would be $w_{ij}P_s$. If it is assumed that the crossflow occurs over one axial node of length Δx, then the crossflow per unit length would be $w_{ij}\ P_s/\Delta x$. It is assumed, however, that a spacer wire is effective in transporting flow from subchannel i to j only over a fraction δ of a spacer pitch. If, therefore, a wire crosses a gap space at x_c, then the forced crossflow is

$$W_{FORCED} = \pi(D+t) \frac{s_{ij}}{A_i} \frac{\delta}{\Delta x} W_i \qquad (2)$$

for $x - \Delta x < x_c < x$.

While Eq. (2) applies only where a wire crosses a gap, it should be noted that COBRA-IIIB uses these crossflows to compute a redistribution of flow so as to satisfy mass and momentum balance equations for each subchannel. In effect, therefore, each gap is assigned a local mixing rate at each axial location.