COMPUTATION OF TURBULENT FLOW AND HEAT TRANSFER IN SUBASSEMBLIES

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INTRODUCTION

This research is carried out in order to provide information on the thermohydraulic behaviour of fast reactor subassemblies.
The research work involves the development of versatile computation methods and the evaluation of combined theoretical and experimental work on fluid flow and heat transfer in fuel rod bundles.

The computation method described here rests on the application of the distributed parameter approach. The conditions considered cover steady, turbulent flow and heat transfer of incompressible fluids in bundles of bare rods. Throughout 1978 main efforts were given to the development of the VITESSE program and to the validation of the hydrodynamic part of the code.

In its present version the VITESSE program is applicable to predict the fully developed turbulent flow and heat transfer in the subchannels of a bundle with bare rods.

In this paper the main features of the code are described as well as the present status of development.

THE MAIN FEATURES OF THE COMPUTER PROGRAM

The finite element method has been adopted to solve the flow and heat transfer problem in a rod bundle. This computational method has the advantage of providing accurate descriptions of complex bundle geometries.

Moreover, regions with large gradients can be easily refined, whereas boundary conditions are expressed in a convenient way.
The idealization of these complicated coolant flow areas can be achieved by introduction of cylindrical and Cartesian coordinate systems.

The flow area of the bundle cross-section is subdivided into quadrilateral and triangular finite elements with nodes at each vertex. In the VITESSE-code finite element meshes can be generated automatically by means of a mesh generator.

In order to solve the resulting set of non-linear equations, both the Newton-Raphson as well as the direct iteration technique are used. The necessary initial guess values are obtained by the solution of the laminar flow problem.

For predicting turbulent fluid flow, additional information on turbulent shear stresses of the flow is required. The turbulent shear stresses have been expressed by Boussinesq's concept of eddy viscosity, derived from numerical models of turbulence. Both the mixing length and kinetic energy models of turbulence are incorporated in the current version of the VITESSE-code. The former model was applied to rod bundle fluid flow by Meyder [1] while the latter was introduced by Wolfshstein [2] for one-dimensional flows. The computational procedures of both models have been applied through the boundary layer right up to the wall. In order to verify the model predictions of the hydrodynamic part of the code, a number of computations has been carried out simulating the experiments of Kjellström [3] and Rehme [4] on rod bundle fluid flow.

In particular, the measured results pertaining to a wall subchannel [4] reveal that the momentum transport is highly anisotropic in the rod bundle fluid flow. The anisotropy of the momentum transport confirms our findings when attempting to adjust the VITESSE-code to the measured results. Improvement of the computational results could only be obtained by introducing anisotropic eddy diffusivity distributions. A detailed comparison of the experimental data with Prandtl's mixing length model predictions is given for a central subchannel [5] and for a wall subchannel [6]. This Prandtl's model of turbulence has the disadvantage of having zero eddy diffusivities in those regions of zero velocity gradients.

To deal with this shortcoming, a kinetic energy model has been applied to predict turbulent flows in subchannels of rod assemblies. Since Wolfshstein's application of this model of turbulence to one-dimensional flows, the model has been modified to include anisotropic effects.
A comparison of the results of the two model predictions with the experimental data shows that the kinetic energy model of turbulence offers the best prospects for the computation of boundary layer flows in undisturbed subchannels of a rod assembly (without spacer grids).

For prediction of temperature distributions in subchannels of a bundle, the sequential solution of the coolant momentum and thermal energy conservation equations are required. The present method of computation has been applied to calculate the 3-dimensional temperature field in rod assemblies using the specified axially invariant 2-dimensional turbulent velocity field. The turbulent heat fluxes are determined through the use of the turbulent Prandtl number.

With the aim to validate the combined fluid flow and heat transfer computer code VITESSE, some calculations have been executed simulating the heat transfer from a fuel rod into a central subchannel as well as the heat transport between these subchannels. The results will serve for the validation of the thermohydraulic part of the VITESSE-code.

APPLICATION OF THE VITESSE PROGRAM

As an example the prediction of the turbulent flow in a 19-rod bundle will be illustrated. The bundle cross-section is shown in fig. 1, which for symmetry reasons is restricted to 1/12 of the flow area. The pitch diameter ratio P/D was 1.3 and that of the dimensionless wall distance (rod centre-wall distance divided by rod radius) W/R = 1.34.
The computations were carried out for a Reynolds number Re = 60,000 based on the hydraulic diameter of the bundle. The bundle sizes and flow conditions described so far pertain to the test section examined by Trippe [7] at KfK.
For the computational simulation of this experiment the finite element idealization shown in fig. 2 has been used. The mixing length model of turbulence has been applied to compute the fully developed turbulent velocity profile in the bundle of bare rods. The computed velocities are normalized with the average velocity value and the results are presented in fig. 3. For comparison, the computed results and the experimental data of Trippe [7] are given in table I and refer to characteristic positions of the bundle cross-section. The measured and calculated results are on the whole in fairly good agreement.

Table I Comparison of relative velocities at different positions

node number*	Relative velocities U/U_b	
	experimental data [3]	mixing-length model [1]
115	1.16	1.17
135	1.25	1.26
360	1.16	1.17
489	1.24	1.25
585	1.14	1.16
714	1.22	1.24
810	1.14	1.15
968	0.88	0.88
1004	1.16	1.18
1065	1.11	1.12
2009	0.82	0.81
2120	0.78	0.75

*node numbering is given in fig. 3

FUTURE WORK RELATED TO THE COMPUTER CODE VITESSE

In view of the lack of information concerning heat transfer in rod bundles, further work will deal with experimental and theoretical investigations on the related temperature fields. The aim of the experiments should be to provide detailed information for the validation of the thermohydraulic part of the VITESSE-code.

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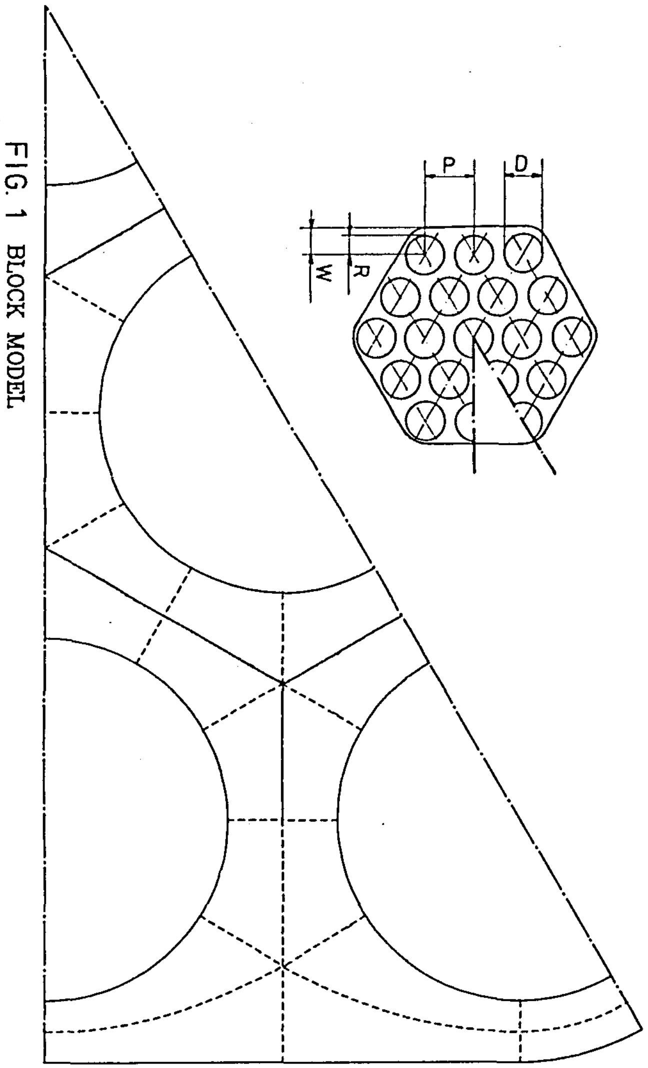

FIG. 1 BLOCK MODEL

19–ROD ASSEMBLY ,TRIPPE.
REYNOLDS NBR. 61191.3

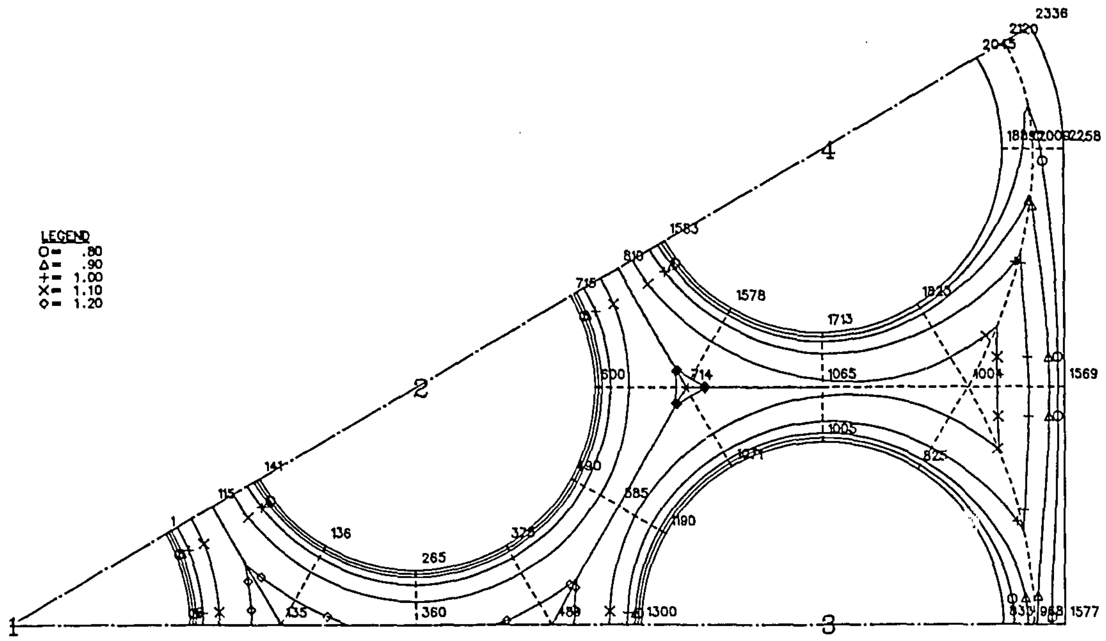

FIG. 3 VELOCITY DISTRIBUTION

19–ROD ASSEMBLY ,TRIPPE.

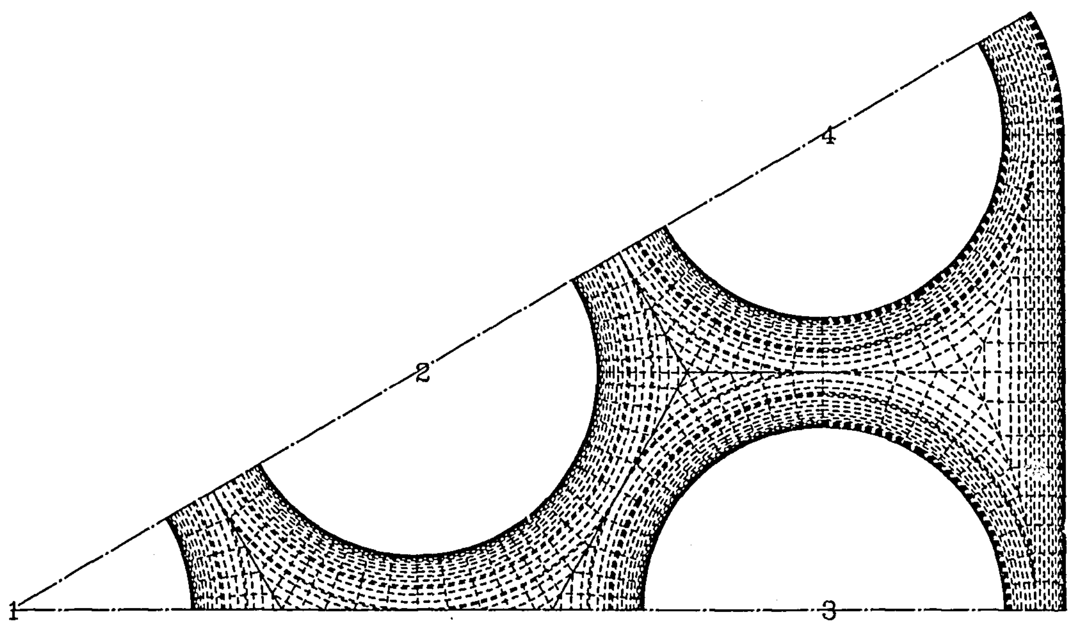

FIG. 2 ELEMENT MODEL