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# ANALYSIS OF STEADY STATE COMBINED FORCED AND FREE CONVECTION DATA IN ROD BUNDLES

MASTER

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Fuel and blanket assemblies in an LMFBR are subjected to a wide range of power and power gradients during their life in the reactor. To accommodate these changes the assemblies operate in a wide range of flow regimes extending from forced convection, turbulent flow, to mixed convection, laminar flow. At low flow conditions the transverse temperature gradient in an assembly is considerably flattened because of energy redistribution by not only wire-wrap mixing and thermal conduction but also by flow redistribution because of buoyancy-induced crossflow. This has significance in LMFBR design, as discussed in Reference 1.

For the mixed convection regime of bundle operation, the transverse velocity profiles within a bundle change axially because of buoyancy-induced crossflow. It was therefore decided to use the ENERGY II(2) and ENERGY III(2) computer programs for the analysis of the rod bundle mixed convection data reported in References 3-5. ENERGY II and III are different in their formulation as ENERGY II neglects the inertial terms in the axial momentum equation and, in addition, the momentum and energy equations are uncoupled. These assumptions impose certain restrictions on the range of applicability of ENERGY II as determined by analysis of the mixed convection data(3-5) (see Reference 1).

The WARD(3) data shows that the exit of heated length transverse temperature profile (max/min temperature across the bundle) reduces from 1.91 at a Reynolds number of 3700, to 1.27 at a Reynolds number of 990, to 1.12 at a Reynolds number of 490 if the power-to-flow ratio, the power skew, and the inlet coolant temperature are kept the same. Figure 1 shows a typical comparison of the ENERGY II, COBRA-IV and the WARD(3) 61-pin blanket assembly data at a Reynolds number of approximately 990. Excellent match between prediction and data was obtained both for the WARD(3) and BNW(4) experiments. The input parameters to the ENERGY II and III codes are the same as determined by analysis of forced convection data (Reference 2). No calibration of the code was done for predicting mixed convection data.

The HEDL(5) 217-pin low flow data was obtained under mixed-convection conditions for a wide range of power skew. The Reynolds number range was from 400-1100. Analysis of the data was not straightforward as it appeared that there is a radial heat loss from the bundle. It was also reported by the authors of Reference 5 that at the low experiment flow rates ($Re \leq 1100$), the flow rate cannot be measured better than 10-15% of the total bundle flow rate. Lack of an accurate estimate of radial heat transfer and bundle inlet flow rate introduced an ambiguity in the analyses of data which required that both inlet flow rate and heat loss be varied in an anticipated range to determine which combination of these two parameters gave best match with data at the six axial levels at which temperature measurements were taken. Table 1 shows the combination of flow and heat loss which gave the best match with data following the aforementioned procedure of data analysis. It was found that for nearly all the HEDL runs the heat loss was not greater than 2-3% of the input energy. The effect of axial conduction on temperature distribution was estimated to be negligible for the HEDL(5) bundle operating conditions. There was considerable mitigation of the radial temperature profiles in the HEDL runs due to conduction and buoyancy-induced crossflow. At low Reynolds number of bundle operation the effect of heat loss at the wall penetrates significantly into the bundle as it causes a significant amount of additional flow redistribution from the wall channels to the central channels and, thus, leads to a further attenuation in the transverse temperature gradient. For typical HEDL power-to-flow ratios it was found that the ENERGY II code, because of the uncoupling of the momentum and energy equations, does not predict well below a Reynolds number of about 400 as it leads to energy balance problems. Comparison of the flow and temperature distribution in the HEDL 217-pin bundle and the geometrically similar ORNL(6) 19-pin bundle under similar operating conditions (power-to-flow ratio, power skew) shows that there is more flow redistribution due to buoyancy in the 217-pin bundle yet, as expected, the temperature gradients across the 19-pin bundle are much smaller.

# REFERENCES

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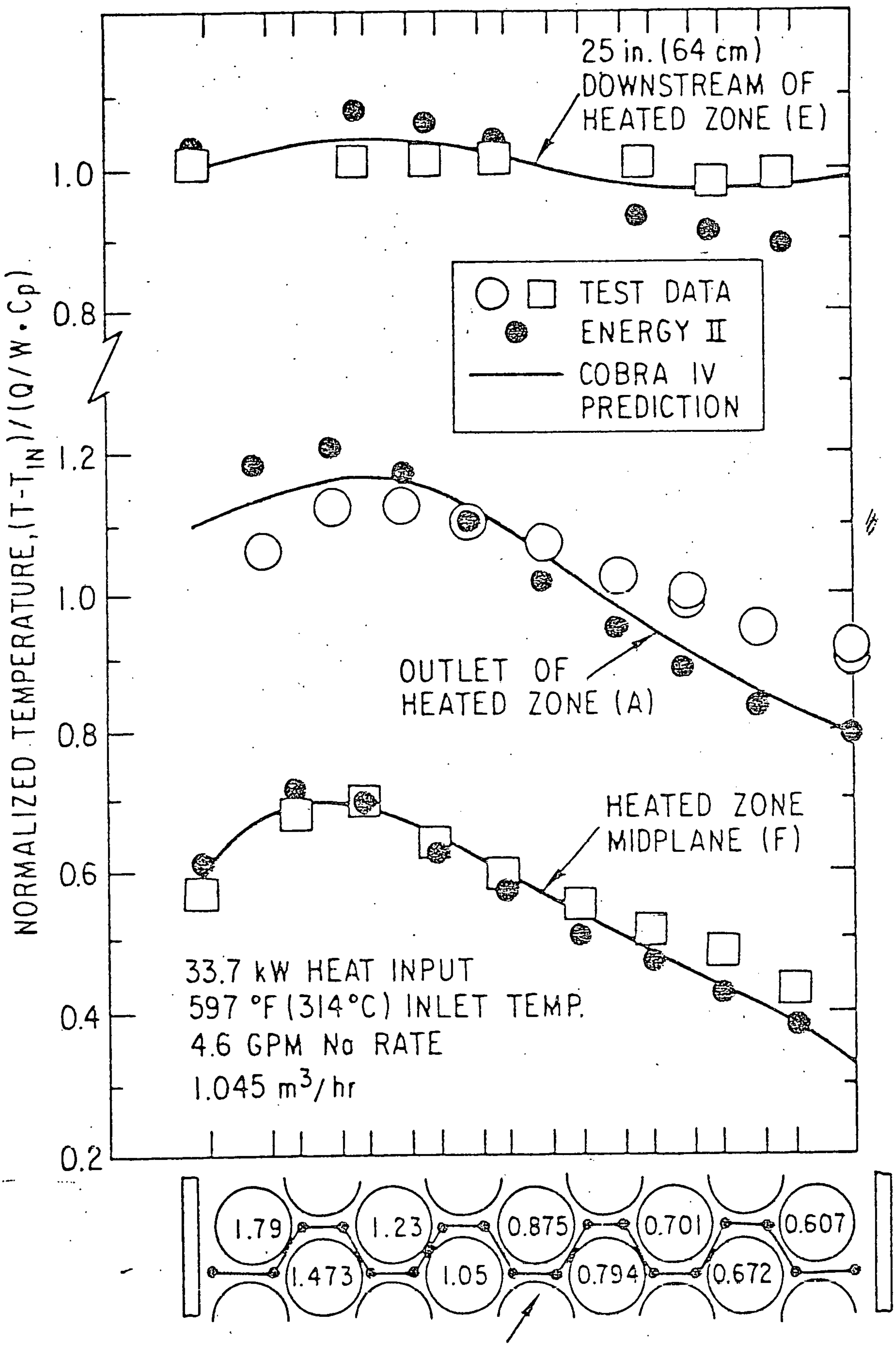

Figure 1. Variation of Normalized Temperature (T-Tin)/ΔT Across the WARD Assembly.

## Table 1. Comparison of Data and ENERGY II Predictions

Run No. 1

DATA ELEVATION: 89.4 in. CODE ELEVATION: 39.4 in.

| | DATA | PREDICTIONS | | | |
|---|---|---|---|---|---|
| CHANNEL NUMBER | TEMPERATURE, °F | FLOW (lb/hr) 2744 | 2860 | 2800 | 2927 |
| | | HEAT LOSS PERCENT 0.0 | 2.2[a] | 4.2[a] | 0.0 |
| 8 | 1067 | 1081.8 | 1060.7 | 1066.6 | 1054.4 |
| 65 | 1069 | 1081.2 | 1060.0 | 1065.9 | 1053.7 |
| 103 | 1090 | 1078.5 | 1057.0 | 1063.0 | 1050.7 |
| 114 | 1061 | 1079.6 | 1058.2 | 1064.1 | 1051.9 |
| 112 | 1061 | 1077.7 | 1056.4 | 1062.3 | 1050.0 |
| 189 | 1057 | 1069.4 | 1047.6 | 1053.5 | 1041.0 |
| 289 | 1035 | 1061.3 | 1038.6 | 1044.3 | 1032.5 |
| 327 | 1042 | 1066.6 | 1043.9 | 1049.5 | 1037.9 |
| 312 | 1039 | 1056.9 | 1034.07 | 1039.6 | 1028.09 |

[a] If you increase flow then Q% heat loss necessary to yield the correct heat balance.