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A SODIUM BOILING DRYOUT CORRELATION FOR LMFBR FUEL ASSEMBLIES

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SUMMARY

Under certain postulated accident conditions for a Liquid Metal Fast Breeder Reactor (LMFBR), such as the failure of the shutdown heat removal system (SHRS), sodium boiling and clad dryout might occur in the fuel assemblies. It is important to predict the time from boiling inception to dryout, since sustained clad dryout will result in core damage. In this paper a dryout correlation is presented.

This correlation is based on 21 boiling tests which resulted in dryout from the THORS Bundle 6A [1], a 19-pin full-length simulated LMFBR fuel assembly and from the THORS Bundle 9 [2], a 61-pin full-length simulated LMFBR fuel assembly. All these tests were performed as follows: for each specified bundle power, an initial steady-state high sodium flow was established, for which sodium boiling did not occur in the bundle. The temperature at the outlet of the test section was ∿ 700°C. Then, using a programmable pump control system, the flow was reduced to a low value and boiling occurred. The flow at the beginning of the transient is called "initial flow," Q.

In order to correlate the data, two separate factors were chosen:

$$K_1 = \frac{P}{Q\rho_{in}\Delta h_{sub}} \quad (1)$$

and

$$K_2 = 1000\,\frac{L}{Nv} = \frac{1000\ LA}{NQ} \quad (2)$$

where P is total input power (kW), Q is initial flow (m^3/s), v is inlet velocity (m/s), ρ_{in} is the density of the sodium at the inlet (kg/m^3), Δh_{sub} is the specific inlet enthalpy subcooling or the difference between liquid saturation and inlet enthalpies of sodium (kJ/kg), L is the perimeter of the bundle housing (m), A is the flow area (m^2) and N is the number of fuel pins in the bundle.

The factor K_1 is dimensionless, and the factor K_2 has the dimension of time (seconds). Factor K_1 is the ratio of the total input power to the power needed to bring all the sodium inlet flow to saturated liquid at the downstream end of the heated section. A value of one for K_1 will produce liquid saturation conditions for the sodium at the end of the heated section. Values larger than one will produce boiling. Values below one will produce only local boiling or no boiling. Boiling-to-dryout times are expected to increase with decreasing values of K_1.

By the trial and error method, the following correlating parameter, I_d, was obtained:

$$I_d = \sqrt{\frac{K_2}{K_1}} \qquad (3)$$

This parameter is plotted in Figure 1 versus dryout time, t_d, defined as the time from boiling inception to dryout. Two distinct regions can be seen for the forced convection and for the natural convection tests. Also, a best estimate fitting curve is shown, with error bands. There is more scatter for the forced convection tests. However, most of the tests are within 25% of the curve.

A two-part correlation was obtained. For forced convection, using the least-squares method for the logarithm of the dryout time, the following expression was obtained:

$$t_d = 10^{0.76\ I_d\ -\ 0.32} \qquad (4)$$

valid for the limits: $1.6 \leq I_d \leq 2.5$ corresponding to a range $8\ s \leq t_d \leq 39\ s$. The least-squares correlation coefficient was 0.76 and the maximum deviation was 31%.

For natural convection, the following curve was fitted:

$$t_d = 10^{0.32\ (I_d)^3\ -\ 0.98\ (I_d)^2\ +\ 2.7} \qquad (5)$$

valid for $2.5 < I_d \leq 3.15$ corresponding to values of t_d in the range $39\ s < t_d \leq 1000\ s$. The least-squares correlation coefficient was 0.85 and the maximum deviation was 29%.

In order to use this correlation, factor K_1 should be calculated first. If this factor is less than one, no boiling occurs. If $K_1 \geq 1$, then factor K_2 and the parameter I_d should be calculated.

If $I_d < 1.6$, $t_d < 8$ s, dryout occurs very rapidly.
If $1.6 < I_d \leq 2.5$, (forced convection run), Eq. 4 applies.
If $2.5 < I_d \leq 3.15$, (natural convection run), Eq. 5 applies.
If $I_d > 3.15$, then $t_d > 1000$ s, a very long boiling time, which can be considered as no dryout.

This correlation was obtained from experimental facilities of 19 and 61 pins, powers from 4.1 to 15.3 kW/pin, inlet velocities between 0.22 and 1.35 m/s, corresponding to inlet flows per pin between 4.6×10^{-6} and 26.3×10^{-6} m^3/s/pin, test section inlet temperatures from 386 to 450°C, boiling temperatures from 913 to 982°C, bundle housing perimeters of 0.11 and 0.20 m and flow areas of 3.7×10^{-4} and 12.9×10^{-4} m^2.

The correlation was evaluated with other non-dryout boiling and non-boiling runs of the same series of experiments and good agreement was obtained. The correlation was capable of predicting if boiling occurred (by using factor K_1), and for how long it could be maintained. Four experimental runs were prematurely terminated by instrumentation malfunction, and the correlation predicts that these runs would have culminated in dryout had they been continued. The correlation has been used to predict boiling and dryout times for ongoing tests being performed in the THORS SHRS Assembly 1 [3]. The values calculated by this correlation were in good agreement with the results from the code LOOP-1 [4].

In conclusion, a correlation to estimate boiling and dryout times of sodium in bundles has been developed. This correlation is of interest as a simple scoping tool for dryout studies. It may be applied to other experimental facilities with similar geometries and test conditions.

REFERENCES

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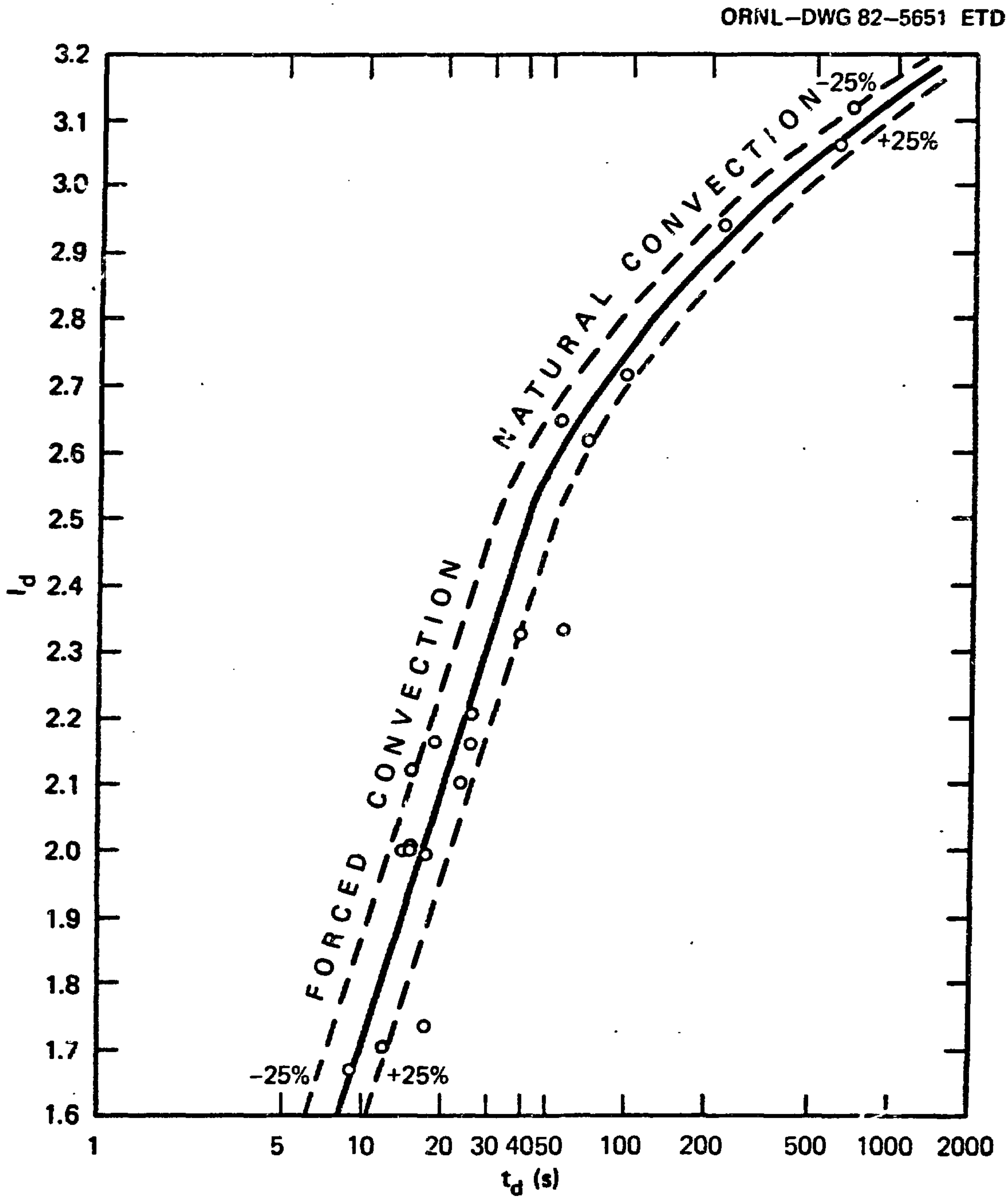
FIGURES

Fig. 1. Sodium Dryout Correlation - I_d parameter versus time to dryout, t_d.


ORNL–DWG 82–5651 ETD
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
I_d
NATURAL CONVECTION
FORCED CONVECTION
–25%
+25%
–25%
+25%
1
5
10
20
30
40
50
100
200
500
1000
2000
t_d (s)