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**A PARAMETRIC STUDY OF RATE OF POWER
REMOVAL FROM HOMOGENEOUS
BOILING REACTORS**

By
L. G. Alexander
S. Jaye

September 20, 1955

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Technical Information Extension, Oak Ridge, Tennessee

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A PARAMETRIC STUDY OF RATE OF POWER REMOVAL FROM
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L. G. Alexander
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OAK RIDGE NATIONAL LABORATORY
Operated by
Union Carbide Nuclear Company
Post Office Box P
Oak Ridge, Tennessee

ABSTRACT

Power density for stable operation was calculated by the method of Zmola and Bailey for a simple reactor model at pressures in the range from 500 to 2500 psi, reactor heights from 10 to 20 ft., mean density decreases from 0.2 to 0.5, and flow resistance "velocity-heads" from 3.0 to 9.0. At 2000 psi, height of 15 ft., mean density decrease of 0.4, head loss of 4.5, the power density predicted was 18.5 kw/liter for the case where the fission rate is uniform throughout the core. By suppressing fissions in the downcomer, this power density can be approximately doubled.

I. INTRODUCTION

Recently, Zmola and Bailey have published an analysis of boiling nuclear reactors⁽¹⁾. They presented a set of equations and charts by means of which the steady state energy removal rate can be computed. Their method of calculation has been applied, in the present paper, to a parametric study of a homogeneous boiling reactor.

II. REACTOR MODEL

The system selected for study is shown diagrammatically in Fig. 1

Fig. 1 Schematic Diagram of Natural Circulation, Boiling, Homogeneous Reactor

The aqueous fuel and bubbles of vapor rise up through a draft tube into vapor separators. The vapor-free liquid then flows into a downcomer. The heat removal rate is expressed in terms of the so-called "power" density,

(1) Zmola, P. C. and Bailey, R. V., "Power Removal From Boiling Nuclear Reactors," ORNL-CF-55-7-43 (55).

P_R , in units of kw. per liter of core volume (including the downcomer).

III. DEPENDANCE OF POWER DENSITY Q ON PRESSURE

In the first study, a reactor height, Z , of 15 feet was selected. A flow energy loss coefficient, K_f , of 4.5 was chosen as typical⁽¹⁾, and the ratios of riser area to downcomer area and of separator inlet area to downcomer area were set at 3.0 and 0.577, respectively⁽¹⁾. The rate of liberation of heat by the nuclear reaction was assumed to be uniform throughout the core (see also Section IV).

The pressure, P , was varied between 500 and 2500 psia, the mean density decrease, δ , was varied between 0.2 and 0.5. The corresponding variation in P_R is shown graphically in Fig. 2, where the calculated points are represented by circles. The scatter in the calculated points is due to errors in judgment in interpolating in the charts presented by Zmola and Bailey. The points are represented reasonably well by straight lines on a log-log plot. There may be some small curvature, but it does not appear to be significant, especially when the simplifying assumptions used by Zmola and Bailey are recalled.

The equation

$$\frac{P_R}{P_{R0}} = \left(\frac{P}{P_0} \right)^{0.725} \left(\frac{\delta}{\delta_0} \right)^{1.55} \dots \dots \dots (1)$$

fits the lines in Fig. 2 reasonably well.

In Fig. 3a through 3e is shown the variation of the power density, P_R , with pressure, P , in the range from 500 to 2500 psi., reactor heights Z of 10, 15 and 20 feet, and mean density decreases, δ , in the range from 0.2 to 0.5.

It is seen that, at a given density decrease, the power density decreases with increasing reactor height. Qualitatively, this follows from the consideration that if K_f is independent of Z (which is nearly so, since the principal loss is in the separators and in turning losses), then the circulation

Fig. 2. Power Density in Reactor 15 ft. High

Fig. 3a. Boiling Reactor ($p = 500$ psia)

Fig. 3b. Boiling Reactor ($p=1000$ psia)

Fig. 3c. Boiling Reactor ($p=1500$ psia)

Fig. 3d. Boiling Reactor ($p=2000$ psia)

Fig. 3c. Boiling Reactor ($p = 2500$ psia)

rate is proportional to $Z^{1/2}$. The total energy removal rate, Q , is proportional to circulation rate. On the other hand, the reactor volume, for a fixed diameter, is proportional to Z . Thus, the power density

$$P_r = \frac{Q}{V} \sim \frac{Z^{1/2}}{Z} \sim Z^{-1/2} \quad \dots \dots \dots (2)$$

When the exponent of Z is calculated from the data of Fig. 3a - 3e, it is found to be closer to $-2/3$ than $-1/2$. This is thought to signify the effect of "slip,"—the condition that the vapor flows relative to the liquid.

IV. EFFECT OF NON-UNIFORM FISSION DENSITY

In the actual reactor, the fission rate will generally be less in the downcomer than in the draft tube. Zmola⁽¹⁾ states that it may be desirable to prevent fissions entirely in the downcomer in order to maximize the total heat output for a given geometry.

The case of non-fission in the downcomer was investigated and the results are shown in Fig. 4. It is seen that a considerable increase in power density is achieved by suppressing fission. For a mean density of more than 0.3, the power density increases by a factor of two or more.

V. EFFECT OF FLOW RESISTANCE

The flow loss coefficient, K_f , measures the energy losses in terms of "velocity heads". Zmola and Bailey selected a value of 4.5 as probable for boiling reactors of the type treated here. In Fig. 5 is shown the variation of power density with K_f at 2000 psi and Z of 15 feet. It is seen that the power density is rather insensitive to changes in K_f , changing by less than a factor of two when K_f is varied from 3.0 to 9.0.

VI. CONCLUSIONS

A typical set of specifications that presently appear reasonable are as follows: Pressure, 2000 psia; height of 15 feet; mean density decrease, 0.30; and flow loss of 4.5 velocity heads. From Fig. 3c, the predicted power

Fig. 4. Effect of Fission in Downcomer on Power Density
($p = 2000$ psia: $Z \approx 15$ ft)

Fig. 5. Effect of Flow Resistance on Power Density
($p=2000$ psia; $Z = 15$ ft)

density is 11.9 kw/liter. For the case where the core diameter equals the height, the total reactor heat output is about 900 mw.

At extreme conditions, boiling, homogeneous reactors of the model studied here are capable of power densities in the range of 20 to 40 kw/liter (depending on the degree of suppression of fission in downcomer), provided the pressure is in excess of 2000 psi, the mean density decrease is greater than 0.4 and the height is less than 10 feet.

SYMBOLS

P	Pressure, psia
P_r	Power density, kw/liter
Z	Reactor height, ft.
δ	Mean density decrease, $\delta = 1 - \bar{\rho}/\rho_f$, where $\bar{\rho}$ is the mean density of fluid in the core, and ρ_f is the density of the liquid.

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