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CF-54-10-176

Subject Category: ENGINEERING

UNITED STATES ATOMIC ENERGY COMMISSION

STAINLESS STEEL UNIVERSITY REACTOR

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October 30, 1954

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Date Declassified: November 29, 1955.

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Printed in USA, Price 15 cents. Available from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

AEC, Oak Ridge, Tenn.

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OAK RIDGE NATIONAL LABORATORY
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STAINLESS STEEL UNIVERSITY REACTOR

I. Statement of the Problem

This study was undertaken to determine the critical mass of a swimming pool type reactor with stainless steel substituted for aluminum in the fuel plates.

Requirements for the reactor are:

A. Fuel plates be less than 50% by weight UO_2--a limitation set by fabrication problems.

B. $k_{eff} \sim 1.05$

C. Power lie between 0.1 and 1 MW.

II. Heat Transfer

A. General Considerations

Standard swimming pool reactor dimensions* were taken except fuel plates had 5-mil bread and 20-mil meat. A cosine distribution of power was assumed. This yields the following expression for the heat released at 1 MW operation in a region from $-x \rightarrow x$, $-y \rightarrow y$, $0 \rightarrow z$:

(1) $$Q(xyz) = \left\{1.795 \times 10^6 \frac{BTU}{hr}\right\} \sin \frac{\pi x}{15} \sin \frac{\pi y}{15} \left\{1 - \cos \frac{\pi z}{23.6}\right\}$$

where x, y, z are in inches and the origin lies in the center of the reactor base plane.

The central element of the 5 x 5 loading served as the basis for design. Though the sides of the fuel elements are open, no cross flow of coolant was considered. This should make the design conservative.

The heat output of the central element is, from (1), 3.43×10^5 BTU/hr

B. Natural Convection

Two equations were solved for velocity:

(2) $$Q = \rho V A c_p \Delta T \times (3.6 \times 10^3 \text{ sec/hr})$$

(3) $$V^2 = \left\{\frac{\rho_c}{\bar{\rho}} - 1\right\} \frac{2gr}{f}$$

* ORNL-991

where

Q = heat transferred, BTU/hr
p = weight density of coolant, #/ft^3
V = coolant velocity, ft/sec
A = area for fluid flow, ft^2
C_p = specific heat at constant pressure, BTU/# - °F = 1 for water
ΔT = temperature rise of coolant through reactor, °F
p_c = weight density of entering coolant, #/ft^3
$\bar{p}$ = average weight density of coolant in reactor, #/ft^3
g = acceleration due to gravity, = 32.2 ft/sec^2
r = hydraulic radius = flow area/wetted perimeter, ft.
$\bar{f}$ = average friction factor of fluid in reactor, dimensionless

Note: $f = f(\frac{DV\bar{p}}{\bar{\mu}})$, a function of Reynold's number.
See McAdams, "Heat Transmission," p. 118
$\bar{\mu}$ = average viscosity of coolant

The Dittus-Boelter equation gave the heat transfer coefficient h:

(4) $$\frac{hD}{k} = 0.023(Re)^{0.8}(Pr)^{0.4}$$

where

h = heat transfer coefficient, BTU/hr - ft^2 - °F
D = equivalent diameter = $4r$, ft
k = thermal conductivity, BTU/hr - ft^2 - °F/ft
Re = Reynold's number = $\frac{pVD}{\mu}$
Pr = Prandtl number = $\frac{\mu C_p}{k}$

Finally, plate surface temperature was computed by

(5) $$T_s = \frac{Q}{ha} + T_f$$

where

T_s = surface temperature, °F
T_f = mean fluid temperature, °F
a = heat transfer area, ft^2

Figure 1 is a plot of central plate surface temperature, assuming non-boiling equations are holding, for 1 MW operation versus the number of plates per element. Note that under 20 feet of water, water boils at 239°F. While obviously non-boiling equations do not hold below 10 plates per element, Figure 1 shows 10 plates per element to be the minimum number for 1 MW operation and natural convection cooling.

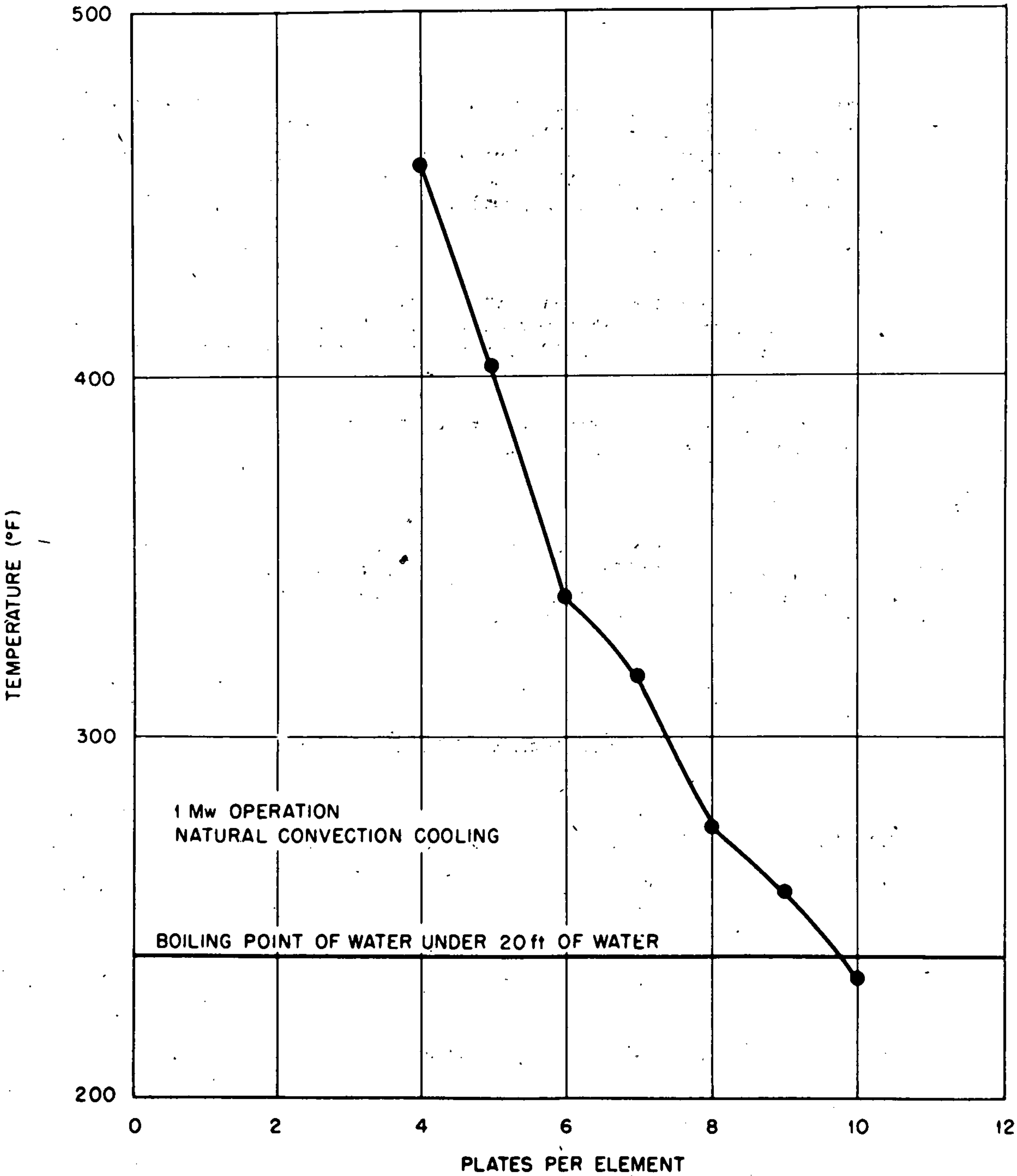

Fig. 1. Central Plate Surface Temperature vs. Number of Plates per Element.

Figure 2 is a plot of maximum power for non-boiling versus number of plates per element. This also shows the effect of adding a 20-foot chimney to the 6 plate system. While the chimney would improve heat transfer, it would also funnel N^{16} to the pool surface, creating a health problem.

C. Forced Convection

If coolant is forced through the core, 1 MW operation is possible at low numbers of plates per element. Figure 3 is a plot of required velocity for 230°F central plate surface temperature versus plates per element.

Figure 4 gives the maximum power for non-boiling as a function of velocity for 2 - 6 plate systems.

III. Critical Mass

Calculations were made on the three-group, three-region ORACLE code, cylindrical model 19-cm radius, 66-cm height, light water reflected on the side. Self-shielding was not considered. Figure 5 shows the results, and Table I gives a summary of the results.

Table I

Summary of Results

Plates/element	k = 1 gm/plate	k = 1.05 gm/plate	k = 1 Critical mass, gm	k = 1.05 Invested mass, gm
2	46	53	2120	2440
3	34	39	2340	2690
4	27	31	2480	2850
5	24	27	2760	3100
6	20	23	2760	3170

NOTE that 50% by weight of U corresponds to ~ 105 gm 25/plate.

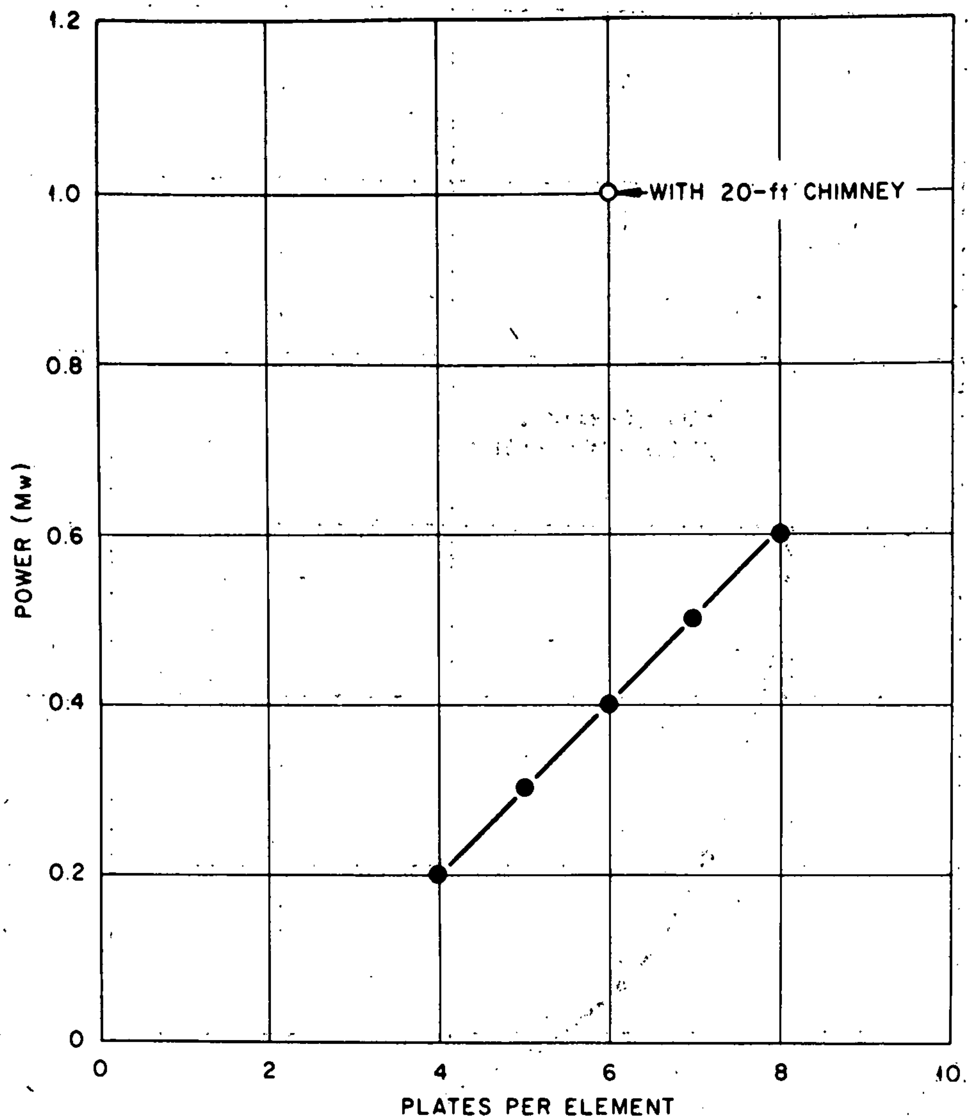

Fig. 2. Maximum Power vs. Number of Plates per Element
(Natural Convection Cooling)

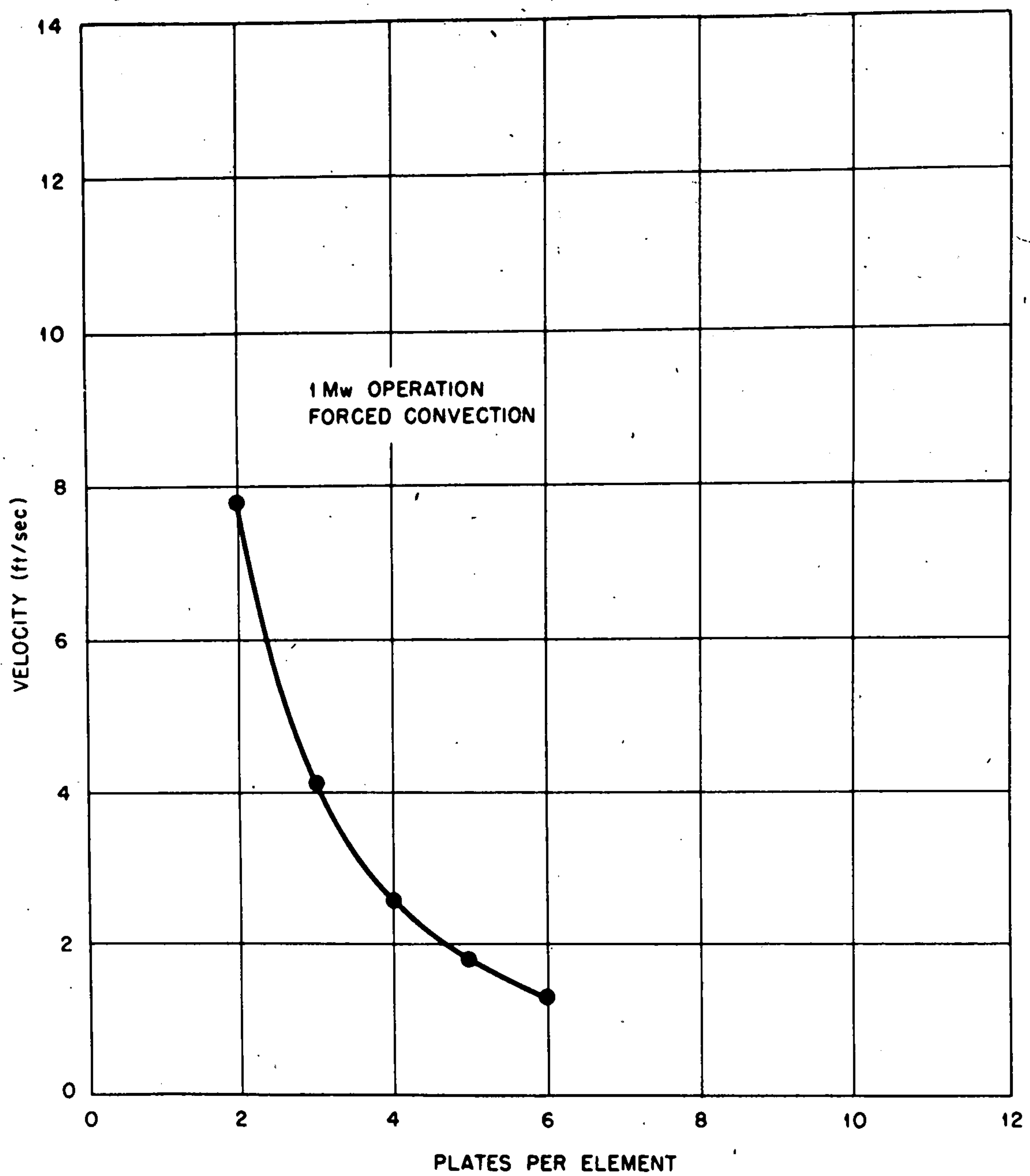

Fig. 3. Velocity for 230°F Central Plate Surface Temperature vs. Number of Plates per Element.

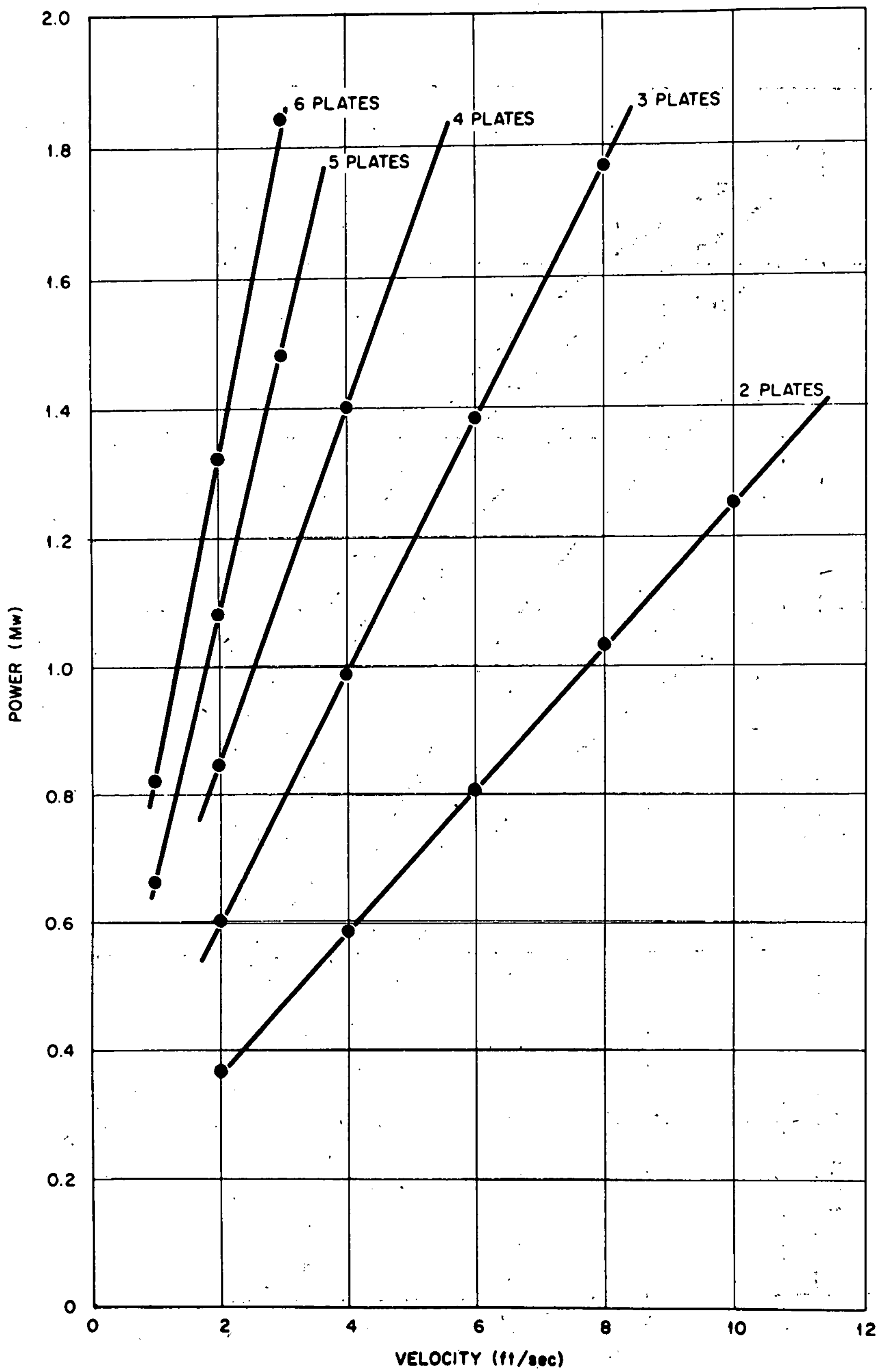

Fig. 4. Maximum Power vs. Velocity (Forced Connection).

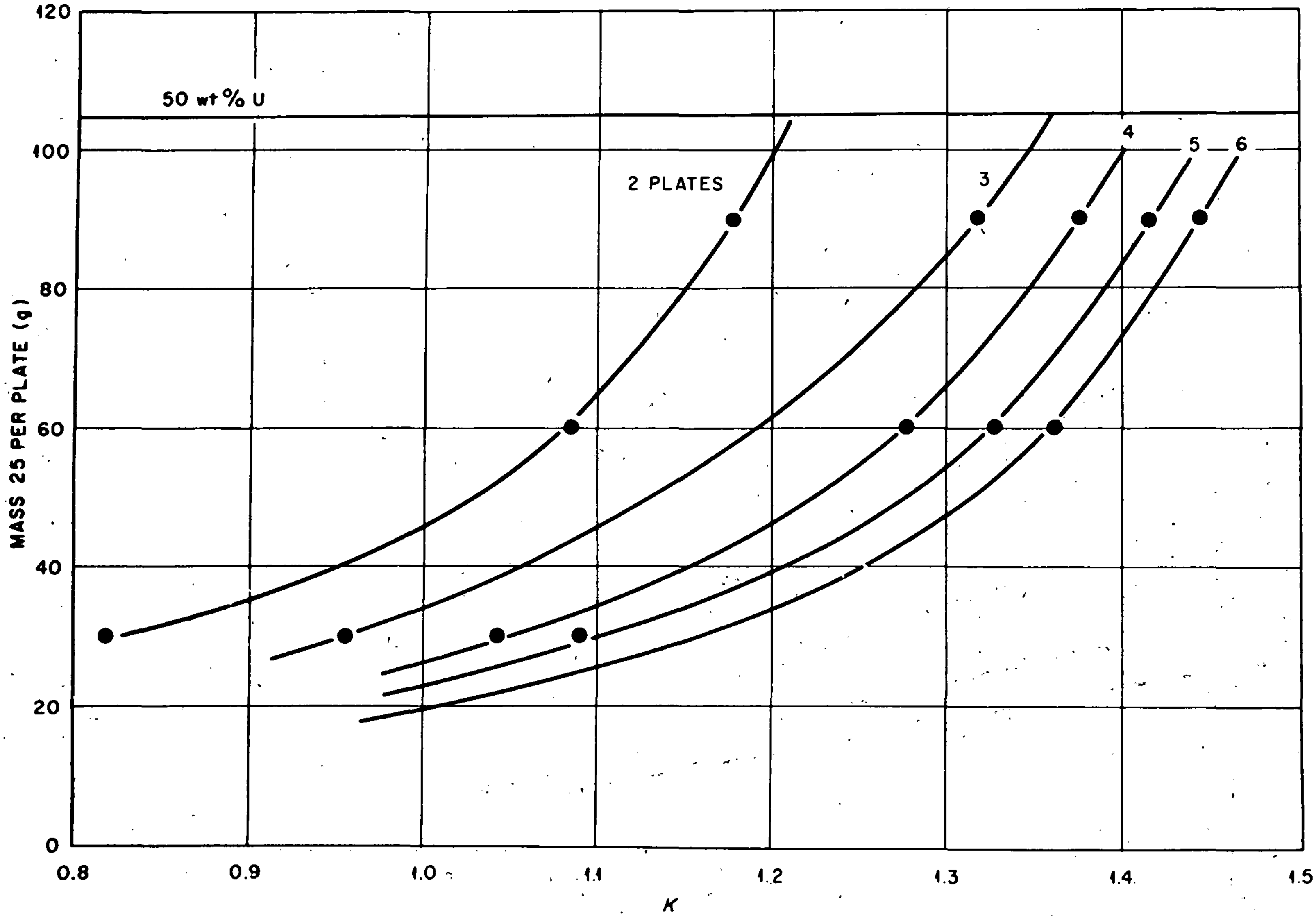

Fig. 5. Mass 25 per Plate vs. *K*; Cylindrical Model, Light Water Reflected.