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576 Mwt Natural Convection Molten Salt Reactor Study

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Abstract

A simplified 576 Mwt natural convection molten salt reactor was studied to determine the approximate size of components and fuel volume.

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Introduction

Studies have been made[1,2] of molten salt natural convection reactors of 5 Mw and 60 Mw thermal output. The following study of a 576 natural convection reactor was made to compare with the family of large molten salt reactors being presently studied.

The chief purpose of this study is to determine the approximate size of the components and fuel volume of the fuel circuit of a 576 Mw natural convection molten salt reactor.

Riser Calculations

For the purpose of this study a rather simple configuration of reactor, heat exchanger, and piping was chosen as shown in Fig. I. All calculations were done on the basis of one heat exchanger and one set of risers and downcomers. Since the frictional losses in the piping are determined primarily by the expansion and contraction losses and are insentitive to wall friction, the single riser can be replaced by a number of risers having the same height and total cross sections. Likewise, the heat exchanger can be replaced by a number of heat exchangers having the same length of tubes and total number of tubes.

The following expression was derived for the height of the riser (see Appendix A).

$$H = \frac{\Delta P \Delta t^2 D^5 + 8\, h_1 D \dfrac{Q^2}{g\rho\pi^2 C_p^{\,2}} + 8\, l f \dfrac{Q^2}{g\rho\pi^2 C_p^{\,2}}}{\alpha \Delta t^3 D^5 - 16\, f \dfrac{Q^2}{g\rho\pi^2 C_p^{\,2}}}$$

Riser Calculations (continued)

Where: H = height of riser - ft (see Fig. I)

ΔP = pressure drop in heat exchanger - lb/ft^2

Δt = temperature drop in heat exchanger $^\circ$F.

D = diameter of riser - ft.

h_1 = loss due to el's, exit and ent of reactor, exit and ent of heat exchanger - 1.6 velocity heads.

Q = power output - 546,000 Btu/sec

g = accel. of gravity - 32.2 ft/sec^2

C_p = specific heat - 0.52 Btu/lb - $^\circ$F

l = 20 ft (see Fig. I)

f = friction factor = .02

α = temperature coefficient of density - 0.0121 lb/ft^3 - $^\circ$F

ρ = density of fuel = 123 lb/ft^3

For an eight foot diameter reactor the volume of the piping will be

$$V_P = \frac{\pi}{4} D^2 (2H + 20 - 8)$$

for each value of ΔP and Δt this volume will be a minimum at some value of D and H.

Fig. II is a plot of piping volume versus riser height for $\Delta t = 200^\circ$ and values of $\Delta \rho$ of 10, 20, 30, 40, and 50 lb/ft^2. Similar plots were made for $\Delta t = 175^\circ$, 225°, and 250°. The minimum values of piping volume and the associated riser heights and diameters are plotted against heat exchanger pressure drop in Figs. III and IV.

Heat Exchanger Calculations

On the basis that the heat exchanger is of the counterflow tube and shell design with the fuel in the tubes and that the Nusselt number over the range

Heat Exchanger Calculations (continued

investigated is constant and equal to 4[3], we derive the following relationships (see Appendix B).

$$LN = \frac{286.5\ Q}{k\,\Delta t_a}$$

$$N = \frac{Q}{\pi C_p \Delta t d^2}\left(\frac{32\ C_p \mu \frac{\Delta t}{t_a} + 12\ K}{g\rho K \Delta P}\right)^{1/2}$$

The volume of the heat exchanger is:

$$V_{HE} = V_{tubes} + V_{Header}$$

$$= \frac{\pi}{4} d^2 LN + \frac{(1.5\ d)^2\ 3\ N}{2}$$

Where:

L = length of tube - ft

N = number of tubes

K = thermal conductivity of fuel. 3.5 Btu/hr - ft - °F

Δt = temperature drop in heat exchanger. °F

Δt_a = average temperature differential. °F

d = tube inside dia. - .05 ft.

μ = viscosity of fuel = $0.174\ e^{\left(\frac{8062}{°F + 460}\right)}$ lb/hr - ft

Q = heat output. Btu/sec

C_p = specific heat of fuel. Btu/lb - °F

ρ = density of fuel = 123 lb/ft^3

From this we can calculate L, N, and heat exchanger volume against heat exchanger pressure drop for different Δt's. The temperatures used were: fuel entering the heat exchanger at 1210°F and leaving at 960°F to 1035°F. The wall temperature was taken as going from 850° to 1050°, giving the following temperature conditions:

Heat Exchanger Calculations (continued)

Fuel Exit Temperature	Δt	Δt_a	$\frac{\Delta t}{\Delta t_a}$
1035	175	172.5	1.014
1010	200	160.0	1.250
985	225	147.5	1.525
960	250	135.0	1.852

The total volume of the system is equal to the volume of the piping plus the volume of the heat exchanger plus 300 ft^3 for the reactor and expansion tank. Fig. V plots riser diameter, heat exchanger tube length and number of tubes, and total volume of the system against riser height.

Discussion

On the basis of this preliminary investigation, large natural convection reactors do not seem to be very attractive. The elimination of fuel pumps seems to be more than balanced by the increase in fuel volume, and number of heat exchanger tubes although it is possible that the large number of heat exchanger tubes can be reduced by using fuel outside of finned tubes. An investigation into the cost of various molten salt reactor types[4] shows the cost of a natural convection reactor to be higher than comparable forced fuel circulation systems.

References

1. Romie, F. E. and Kinyon, B. W., "A Molten Salt Natural Convection Reactor System", ORNL-CF 58-2-46

2. Zasler, J., "Experimental 5 Mw Thermal Convection Molten Salt Reactor", ORNL-CF 58-6-66

3. McAdams, W. H., "Heat Transmission", McGraw-Hill Book Co., Inc., 3rd Ed. (1954), pp. 229-239

4. Whitman, G. D., "Molten Salt Reactor Cost Study", ORNL-CF 58-8-50

Appendix A

Hystrostatic head for flow $= \frac{\alpha \Delta tH}{\rho}$

Friction loss in piping $= f \frac{l'}{D} \frac{V^2}{2g} + h_1 \frac{V^2}{2g} + h_e$

Where: $l' = 2H + l$

$$V = \frac{4Q}{\pi \rho C_p \Delta t D^2}$$

$$\Delta P = h_e \rho$$

$$\alpha \Delta tH = \frac{16\ Q^2}{2g\pi^2 \rho C_p{}^2 \Delta t^2 D^4} \left(\frac{2\ fH}{D} + \frac{fl}{D} + h_1 \right) + \Delta P$$

$$H = \frac{\Delta P\ \Delta t^2 D^5 + 8 h_1 D \left(\frac{Q^2}{g\rho\pi^2 C_p{}^2} \right) + 8\ lf\ \frac{Q^2}{g\rho\pi^2 C_p{}^2}}{\alpha \Delta T^3 D^5 - 16\ f \left(\frac{Q^2}{g\rho\pi^2 C_p{}^2} \right)}$$

Appendix B

$$\frac{h_a d}{K} = 4$$

$$q = WC_p \Delta t = h_a \pi dL \Delta t_a$$

$$h_a d = \frac{WC_p \Delta t}{\pi L \Delta t_a} = 4\ K$$

Where:

$$W = \text{lb/hr per tube} = \frac{3600\ Q}{NC_p \Delta t}$$

$$\frac{3600\ Q}{\pi LNK \Delta t_a} = 4$$

$$LN = \frac{286.5\ Q}{k \Delta t_a}$$

head loss in heat exchanger - $h_x = \dfrac{64 \dfrac{\mu}{3600} vL}{2g\rho d^2} + 1.5 \dfrac{v^2}{2g}$

Where:

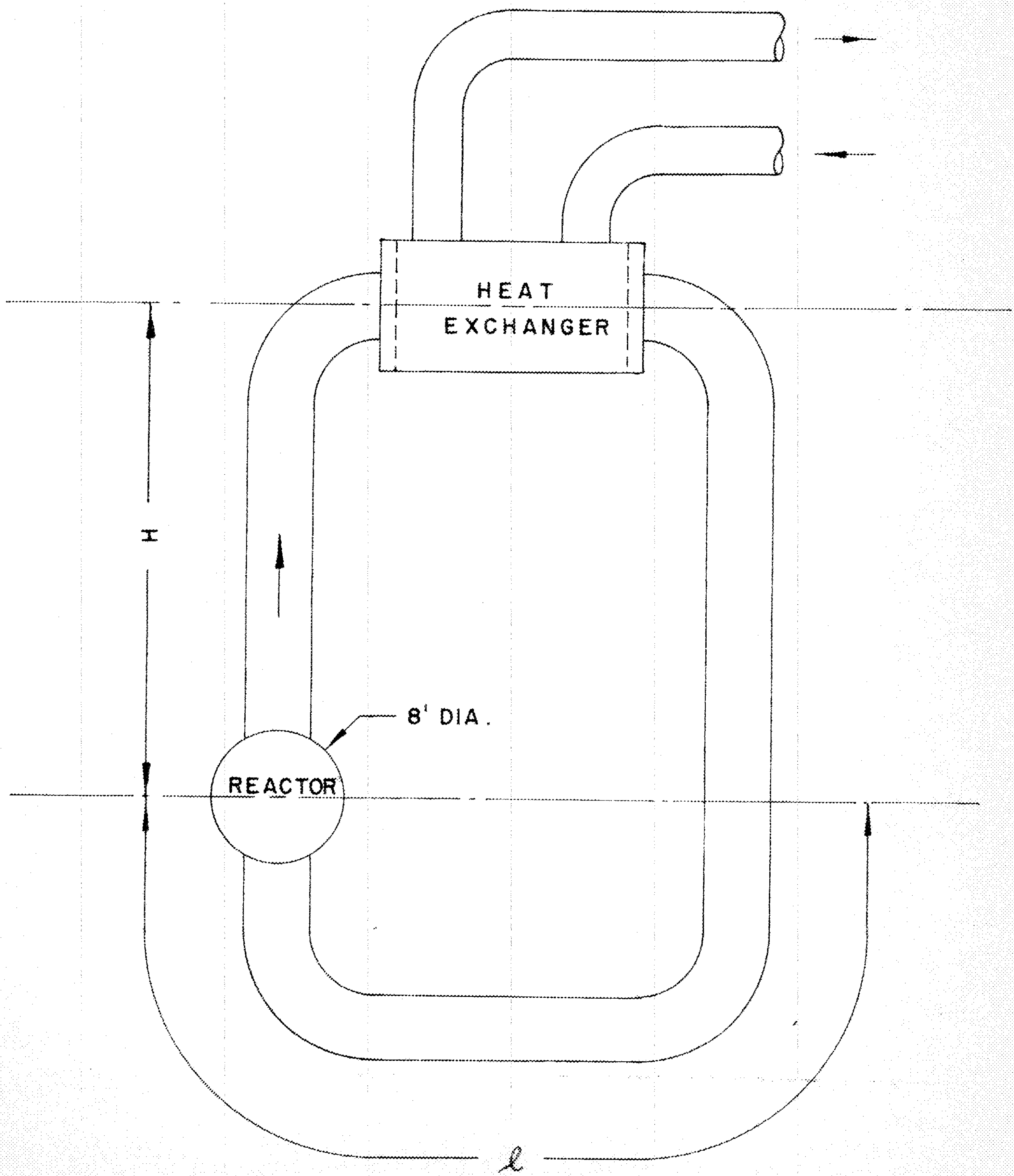
$$v = \frac{4Q}{\pi N\rho d^2 C_p \Delta t}$$

$$h_x\rho = \Delta P = \frac{4 \times 64 \times \dfrac{\mu}{3600} QL}{2g\pi N\rho d^4 C_p \Delta t} + \frac{1.5 \times 16\ Q^2}{2g\pi^2 N^2 \rho d^4 C_p{}^2 \Delta t^2}$$

$$LN = \frac{g\rho\pi^2 C_p{}^2 \Delta t^2 N^2 d^4 \Delta P - 12\ Q^2}{128\ \pi C_p \Delta t \dfrac{\mu}{3600} Q} = \frac{3600\ Q}{4\pi K \Delta t_a}$$

Appendix B (continued)

$$N = \frac{Q}{\pi c\rho \Delta t d^2}\left(\frac{32\ C_p \mu\ \frac{\Delta t}{\Delta t_a} + 12\ K}{g\rho K \Delta P}\right)^{1/2}$$



- Fig. I -

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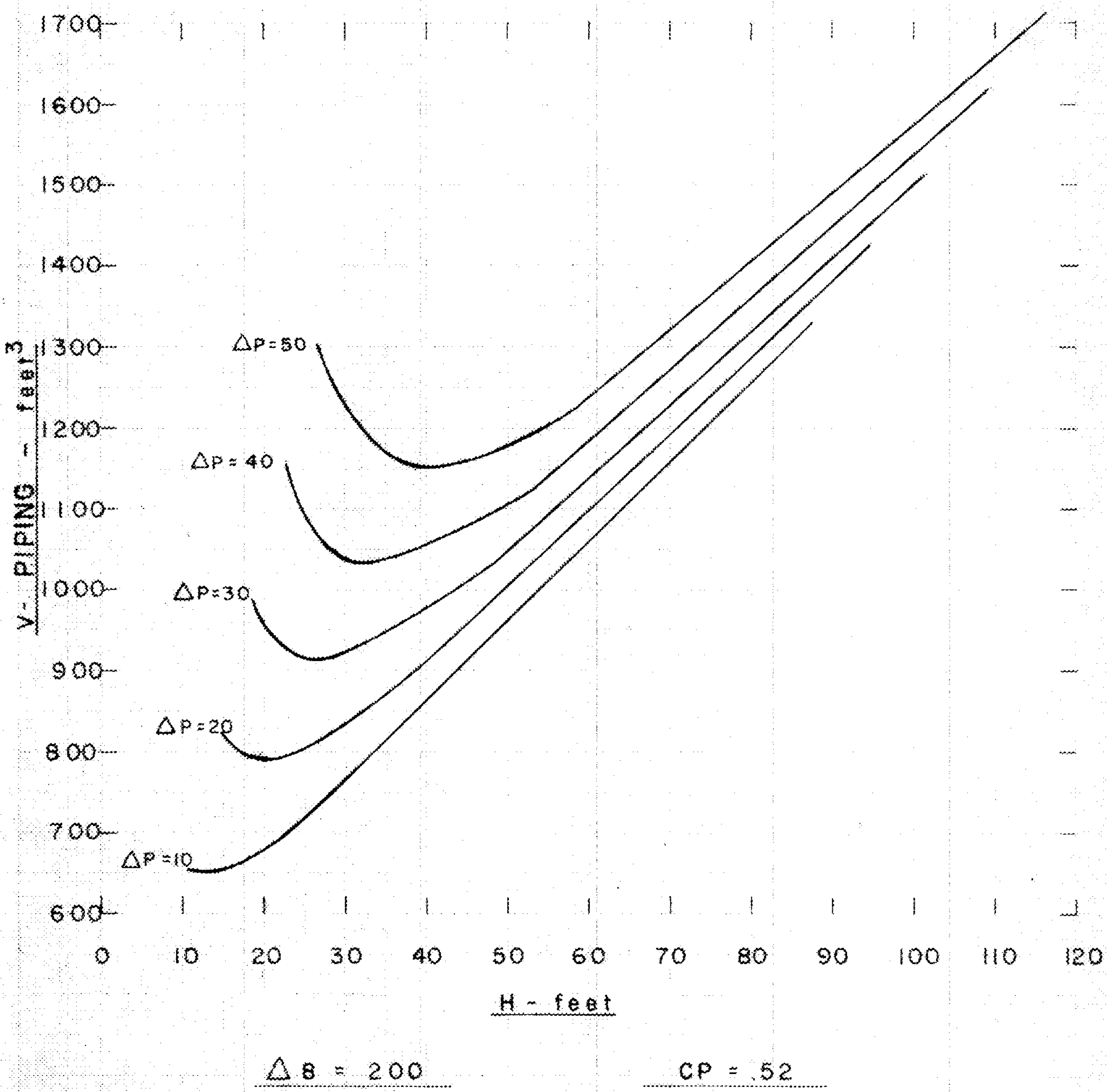

— Fig. II —

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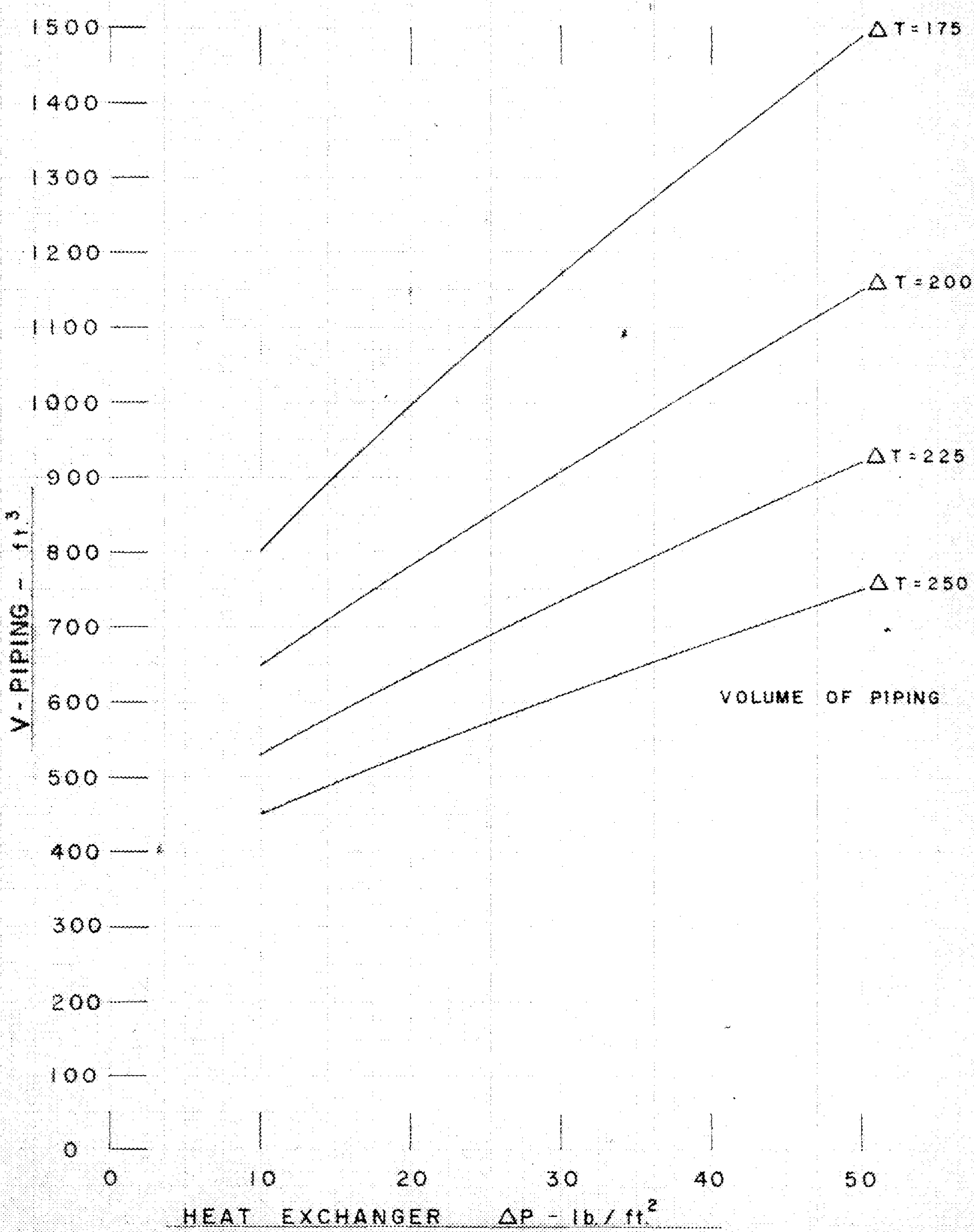

— Fig. III —

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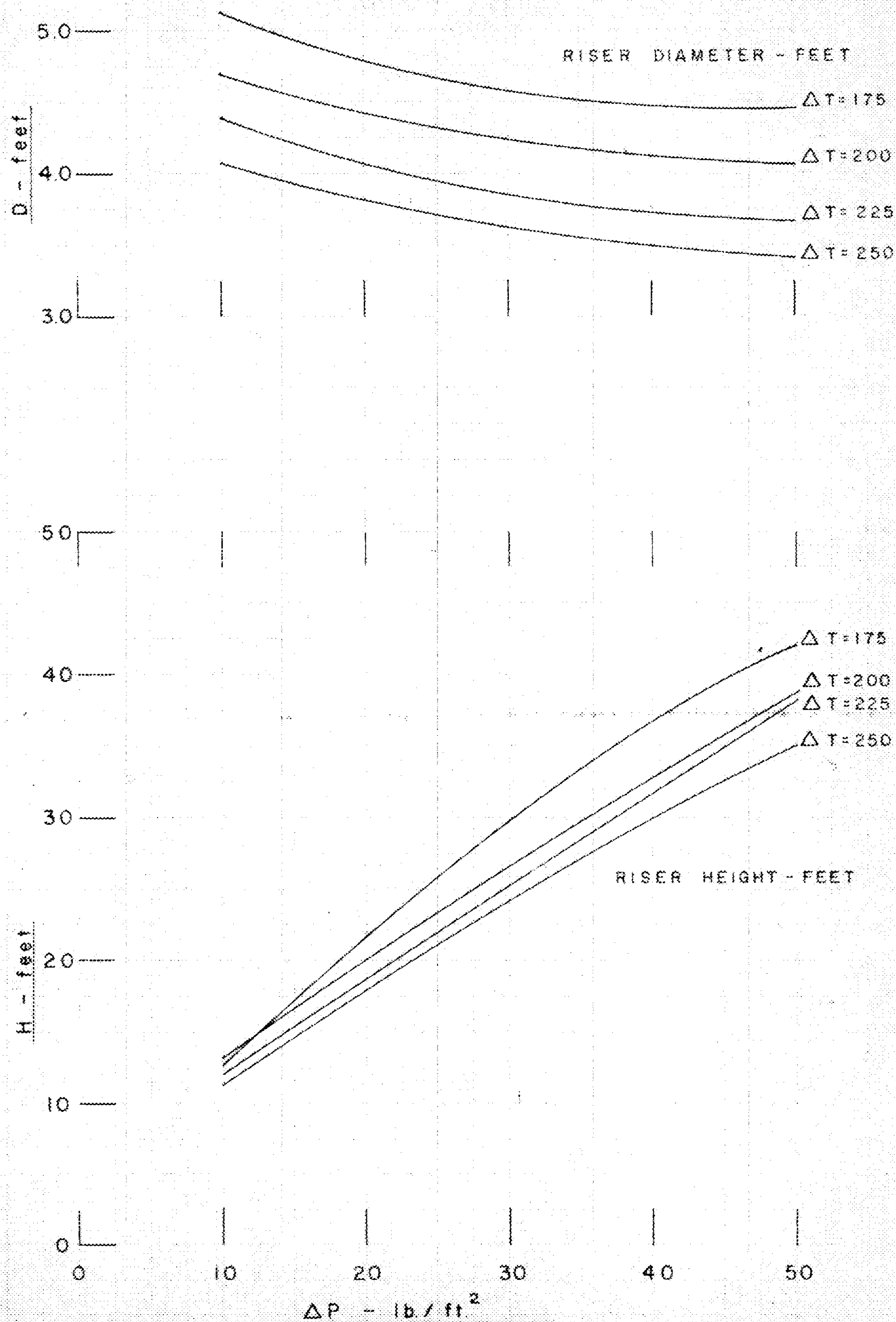

- Fig. IV -

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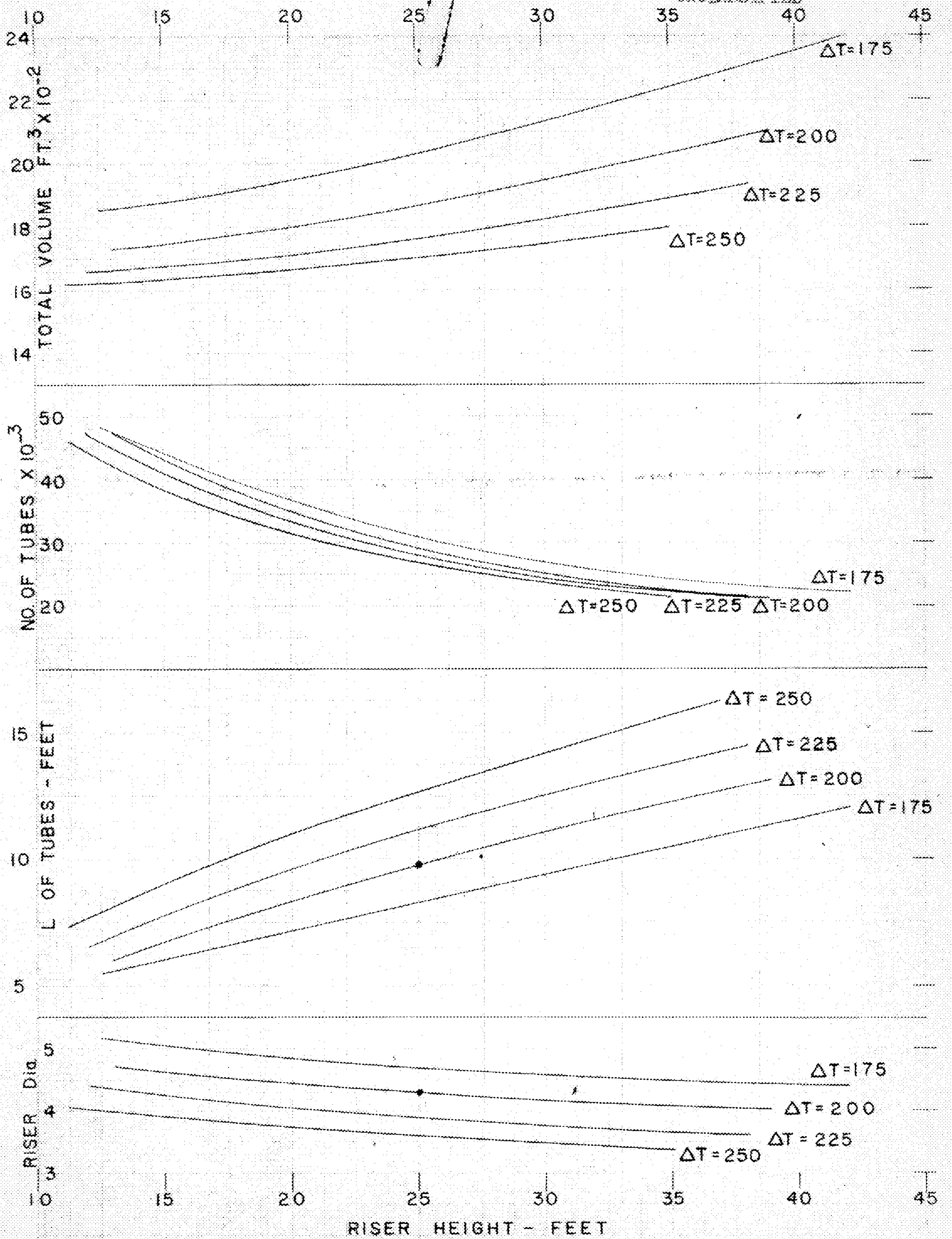

— Fig V —

Distribution

1-3. DTIE, AEC
4. M. J. Skinner