THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Engineering Mechanics

Final Report

TESTS ON MODELS OF NUCLEAR REACTOR ELEMENTS

V. Head Losses in Core Subassembly "C" and Miscellaneous Tests

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UMRI Project 2431

under contract with:

ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.
DETROIT, MICHIGAN

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE ANN ARBOR

August 1959

ABSTRACT

Head losses have been determined for flow through core sub-assembly "C" consisting of an entrance nozzle, a lower axial blanket section, the core section, an upper axial blanket section, and a short section containing the handling lug.

Miscellaneous tests were conducted for (a) the determination of the head loss in the hydraulic model of a nuclear element (to be tested in SRE) and the control of the flow through this model with orifices, (b) the division of flow in a core section with an inner envelope, (c) the determination of the head loss in a core section with spiral springs as spacers, (d) the comparison of head losses in the nozzle and lower blanket sections of the first and second axial blanket subassemblies, and (e) the determination of the head-loss coefficient for distributing orifices of various sizes mounted in a model of a pair of nozzles of the outer radial blanket.

The results of other tests, concerning the study of flow through elements of a nuclear reactor, have been described in four interim reports previously issued.

A. INTRODUCTION

Several laboratory tests on the flow through elements of a nuclear reactor were conducted at The University of Michigan for Atomic Power Development Associates, Inc., since September 15, 1955. The experiments were carried out in the fluid mechanics laboratory of the Department of Engineering Mechanics under an agreement between UMRI and APDA.

The results of previous tests are described in the following four interim reports.

1. In the first report,[1] Head Losses in Blanket Subassembly, laboratory measurements are presented for flow through a model of a radial blanket subassembly of the proposed APDA reactor; these measurements included head losses for the radial blanket element and for the various distributing orifices.

2. In the second report,[2] Studies of Diffusion, a study of diffusion is presented which was carried out in an effort to estimate the distribution of temperature in a nuclear reactor element. Measurements of diffusion of dye in a model of a radial blanket element were used to estimate the diffusion coefficient.

3. In the third report,[3] Head Losses in Core Subassemblies, measurements of head losses for flow through models of various proposed core subassemblies are presented. Six core sections and two axial blanket subassemblies are compared on the basis of drop in piezometric head or pressure drop.

4. In the fourth report,[4] Model Study of Fuel Element Supports, an experimental study is presented of the head losses for flow through a bundle of fuel-element rods supported by four different forms of supports at variable spacings. The drag coefficient for the several types of supports tested were computed from the measurements of the pressure drop; the influence of the boundary proximity was also determined.

In the present, final report, the head losses for flow through the core assembly "C" and the results of miscellaneous tests are presented.

The core subassembly "C," used in the laboratory tests, was a special take-apart model of the reactor elements designed by APDA for the Enrico Fermi Atomic Power Plant. The head loss for the complete core subassembly and the losses for the different sections of it were determined using water as fluid The results are plotted against the core section and blanket section Reynolds numbers. In addition, the total drop in piezometric head, expressed in psi, for the complete core subassembly is plotted against the discharge of sodium in gpm to provide a design plot.

The miscellaneous laboratory tests can be described as follows.

(a) Tests were conducted to determine the head loss in the hydraulic model of a nuclear element, to be tested in an existing nuclear reactor (SRE), and to obtain data for the control of flow through the model by orifices of various sizes. The head loss across the complete element was determined, and the results are plotted against the core section Reynolds number for various orifice sizes. Also, the flow of sodium in lb/hr is plotted against the drop in piezometric head, expressed in psi, and the size of the orifices.

(b) Additional tests were run to determine the proportion of the total flow in the annular space between the container and the inner envelope of the Hydraulic Model No. 4 core section. The spiral spacer windings were of the "Modification No. A" type set at three different spiral angles. The ratio of the flow around the inner envelope to the total flow is presented as a function of the Reynolds number of the core section for different spiral spacer angles.

(c) Tests were conducted to determine the feasibility of using spiral springs as spacers and supports for the core-section rods. The head loss in a core section with this type of spacer was measured using water as fluid. The results of the tests are plotted as a function of the core section Reynolds number.

(d) To supplement the data presented in the third report,[3] additional tests were run to provide data for the comparison of the head losses in the nozzle and lower blanket sections of the first and second axial blanket subassemblies. The results indicated the proportionate reduction of the head loss due to the streamlining of the nozzle and that due to the streamlining of the lower axial blanket.

(e) The head losses for flow through distributing orifices of various sizes mounted in a model of a pair of nozzles of the outer radial blanket were determined in a series of tests. The results are presented in plots of the head-loss coefficient K_o versus the orifice Reynolds number for various orifice sizes.

B. CORE SUBASSEMBLY "C"

DESCRIPTION OF EXPERIMENTAL TESTS

The core subassembly "C" used in the experimental tests was a take-apart full-size model fabricated from stainless steel. It was designed by members of the staff of APDA, and constructed commercially. Detailed description of the model is given in the APDA assembly drawing No. 6XN-1751. The distinguishing features of the model are as follows:

(a) The entrance-nozzle transitions in flow areas, from one round section to another round section and from round to square section, were gradual and well rounded.

(b) The lower and upper axial blanket sections consisted of 16 rods, 0.443 in. in diameter, the ends of which were rounded to an ogival shape. The rods were located on the periphery of the section and close to the casing, thus leaving the core of the flow section completely unobstructed. The open area of a section containing the 16 rods was 0.0246 sq ft and the equivalent diameter of the section, 0.0358 ft (for calculations see Appendix).

(c) The core section consisted of 144 rods, 0.158 in. in diameter, arranged in a square array of 12 by 12 and without an inner envelope; the rods were supported every 2 in. in each transverse direction by grids made up of either 5 or 6 wires 0.042 in. in diameter; the grid wires were bent to a V-shape, with the sides of the V at 45° with the direction of the flow and pointing downstream. Four longitudinal wires, 0.047 in. in diameter, supported the grids at the corners. The open area of a section containing 144 rods without grids was 0.022 sq ft and the equivalent diameter of the section, 0.0129 ft (for calculations see Appendix).

(d) The handling lug, at the end of the upper axial blanket section, had gradual changes in cross sections to minimize head losses.

The test circuit of the laboratory, to which the model was attached, has been described in detail in the previously published third interim report.[3] The location of the piezometer openings, however, being different in this model, is shown in Fig. 1. Also, the locations of two hose adaptors, used to attach the model to the test circuit, are shown in the same figure.

RESULTS OF EXPERIMENTS

In Fig. 2 the drop in piezometric head for the complete core subassembly (between piezometer openings 1 and 12) divided by the square of the discharge is plotted as a function of a Reynolds number based on the open area and equivalent diameter of a cross section through the <u>core</u>. The quantity $\Delta h/Q^2$, although it is not dimensionless, is used in place of the usual friction factor f; rearrangement of the Darcy-Weisbach equation yields the definition equation for this quantity as

$$\frac{\Delta h}{Q^2} = f\left(\frac{L}{2gA^2d_e}\right) = f\left(\frac{8L}{g\pi^2d_e^5}\right),$$

in which the terms within the parentheses are constant with A denoting the open area and d_e the equivalent diameter. Since Δh includes several local losses occurring in the entire core subassembly, the conventional meaning of f would

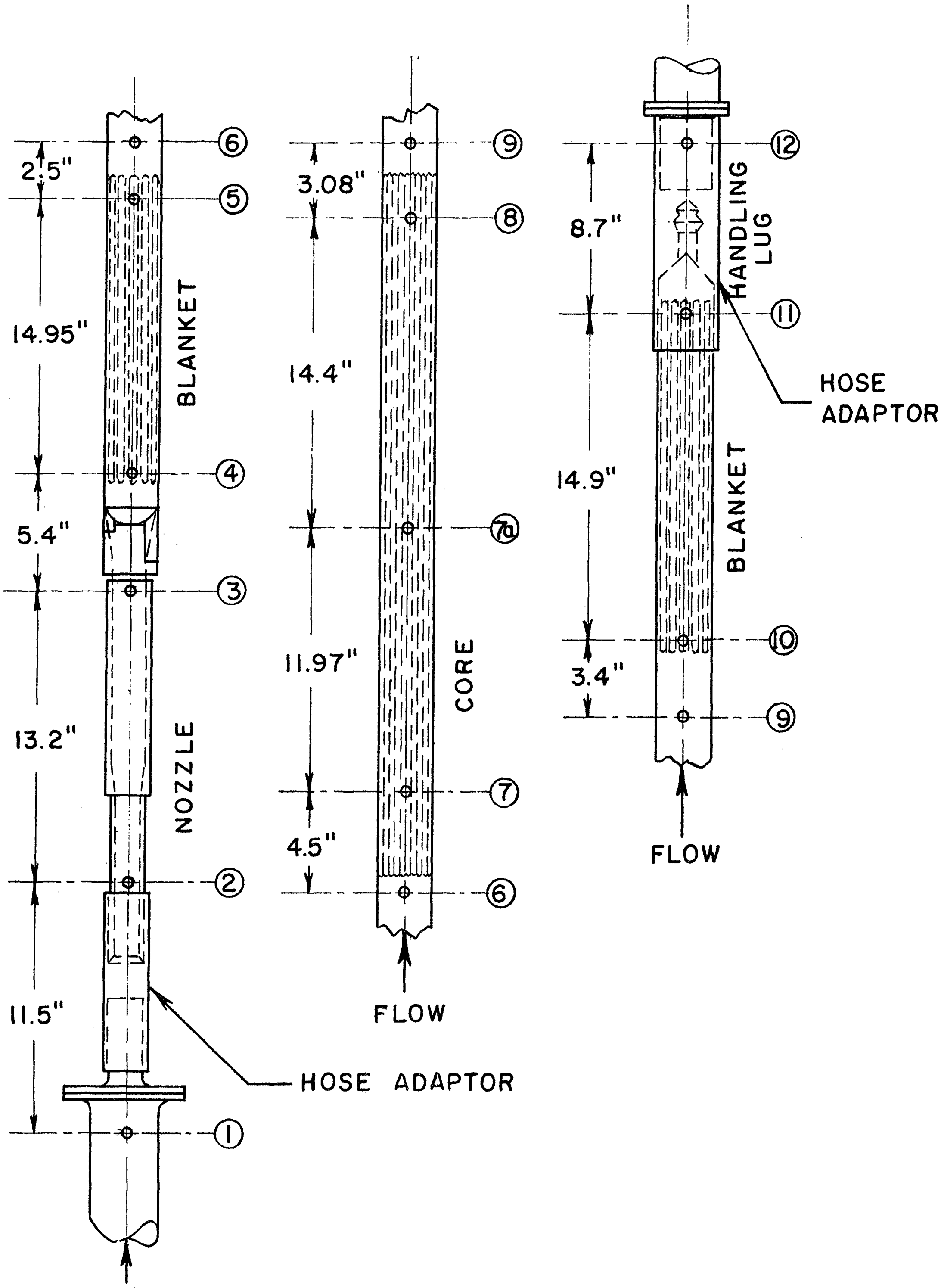


Fig. 1. Location of piezometer openings in core subassembly "C."

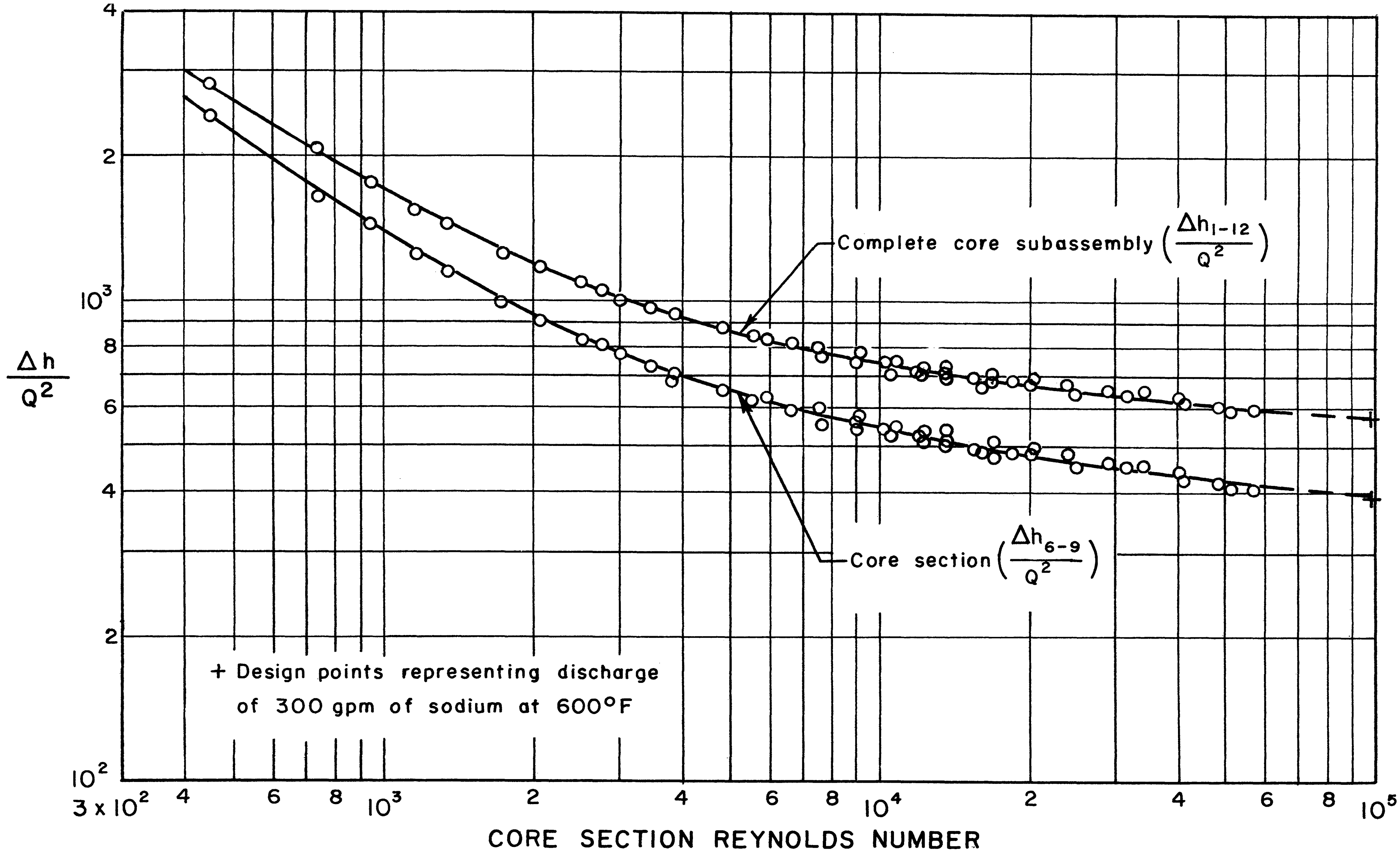


Fig. 2. Drop in piezometric head for complete core subassembly "C," and for its core section only.

be altered in this instance. For large discharges the changes in piezometric head were so great (greater than 85 ft of water) that they were subdivided by using piezometer opening 7a as an intermediate point.

In the same figure the $\Delta h/Q^2$ for the core section only (between piezometer openings 6 and 9) is plotted as a function of the core section Reynolds number. Design points representing a discharge of 300 gpm of sodium[5] at 600°F are shown on each curve.

It should be mentioned that, since the flow areas at piezometer openings 1 and 12 are the same, the drop in piezometric head between these openings is also the head loss. Likewise, the flow areas at piezometer openings 6 and 9 are the same and the drop in piezometric head in this case too is the head loss. Thus, for a given core section Reynolds number, the difference in $\Delta h/Q^2$ obtained from the curves of Fig. 2 indicates not only the magnitude of this quantity for the nozzle and axial blanket subassembly, but the head loss divided by the square of the discharge as well.

In Fig. 3 the drop in piezometric head per foot of length of the core section is plotted as a function of the core section Reynolds number. This represents the head loss, per foot of length, for flow through 144 rods supported by V-shaped grids; it was obtained by dividing the quantity $\Delta h/Q^2$, for piezometer openings 7 to 8, by the distance between them. For comparison, two other curves are shown in the same figure, one for the head loss for flow through the same number of rods but without grids, and the other for a smooth pipe of a diameter equal to the equivalent diameter of a section through the rods. This comparison clearly indicates that the large head loss in the core section is primarily due to the presence of the support grids.

In Figs. 4-6 head losses through different parts of the core subassembly "C" are shown. The head loss is indicated by the quantity h_L/Q^2 computed by using Bernoulli's equation, the collected data on piezometric head, and the velocity heads at the particular sections at which the piezometer openings were located. In computing the velocity head, it was assumed that separation of flow did not occur at regions close to the openings.

In Figs. 4 and 6 the losses are plotted as functions of the blanket section Reynolds number computed on the basis of the open area and equivalent diameter of a flow section through the blanket rods. The head losses between piezometer openings 2 and 3, and 3 and 4, in these figures, were estimated because the actual measurements of the drop in piezometric heads were found to be in considerable error; faulty construction of piezometer opening 3 was the source of this error. The estimated head losses are based on a 30° (total angle) enlargement, and a section of smooth pipe 13.2 in. long. The head-loss coefficient for the enlargement, and the friction factor for the smooth pipe, were taken from standard references.[6,7]

In Fig. 5, the head losses through parts of the core section of the subassembly are presented as functions of the core section Reynolds number. The head

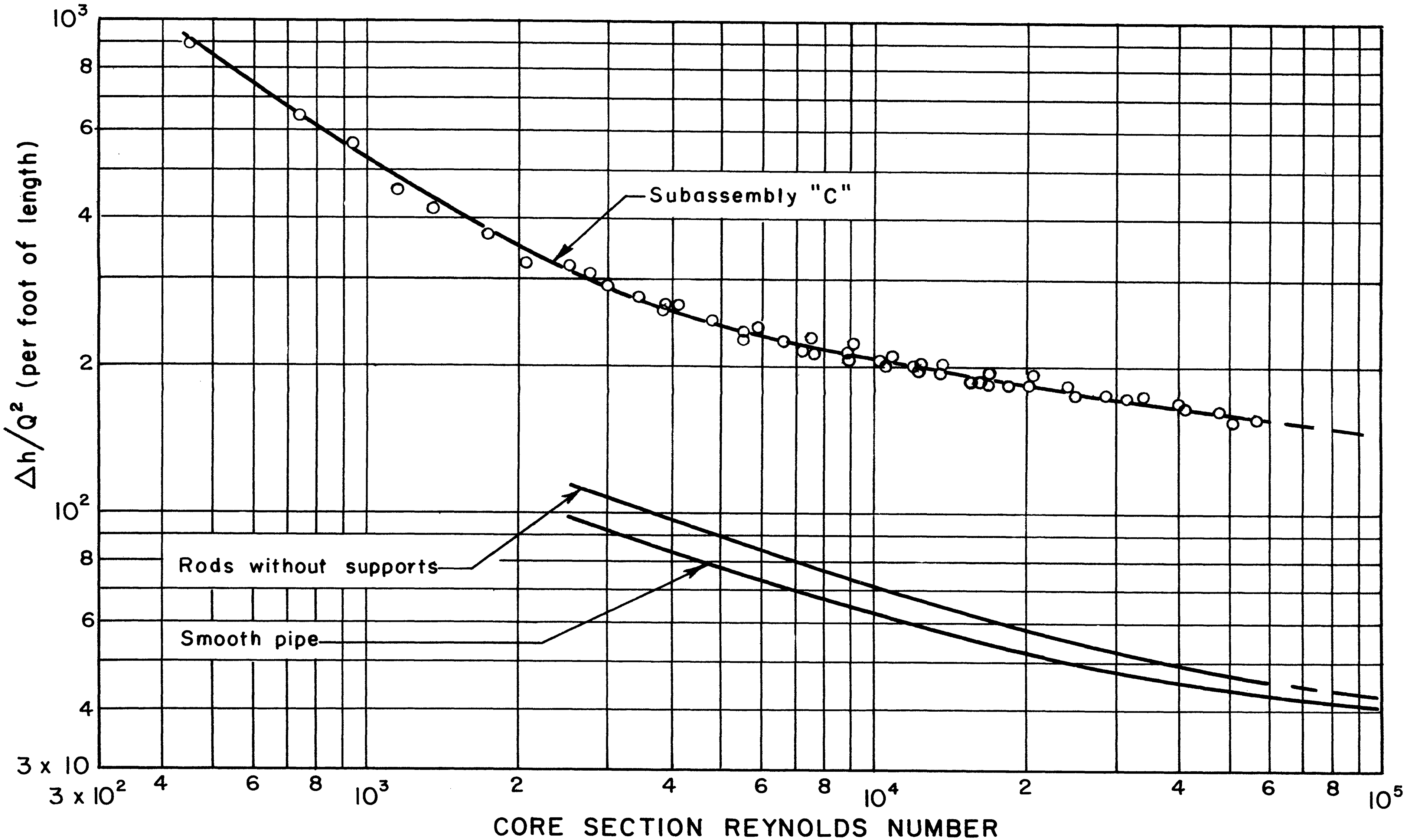


Fig. 3. Drop in piezometric head per foot of length in core section of subassembly "C," entrance losses excluded.

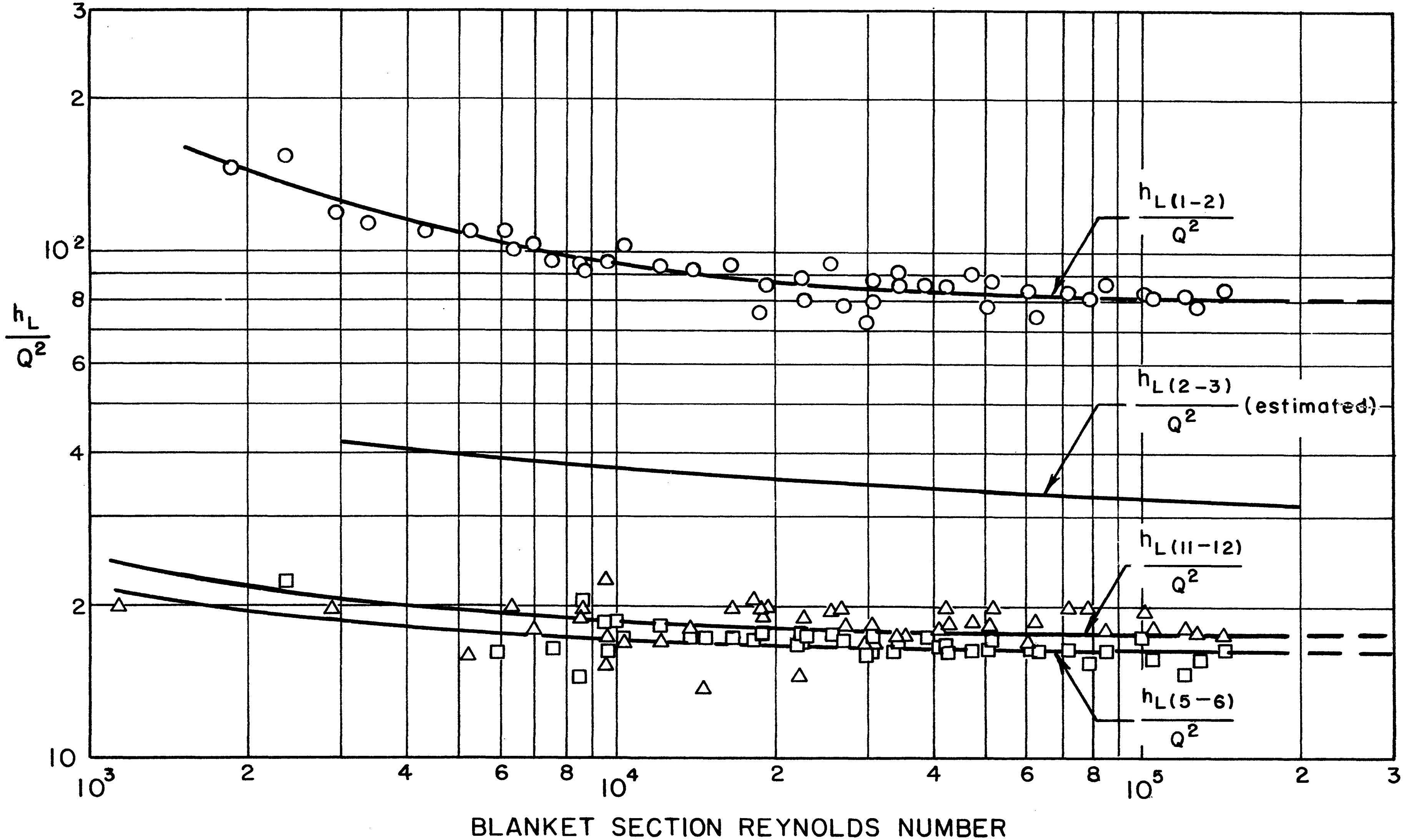


Fig. 4. Head losses through parts of core subassembly "C."

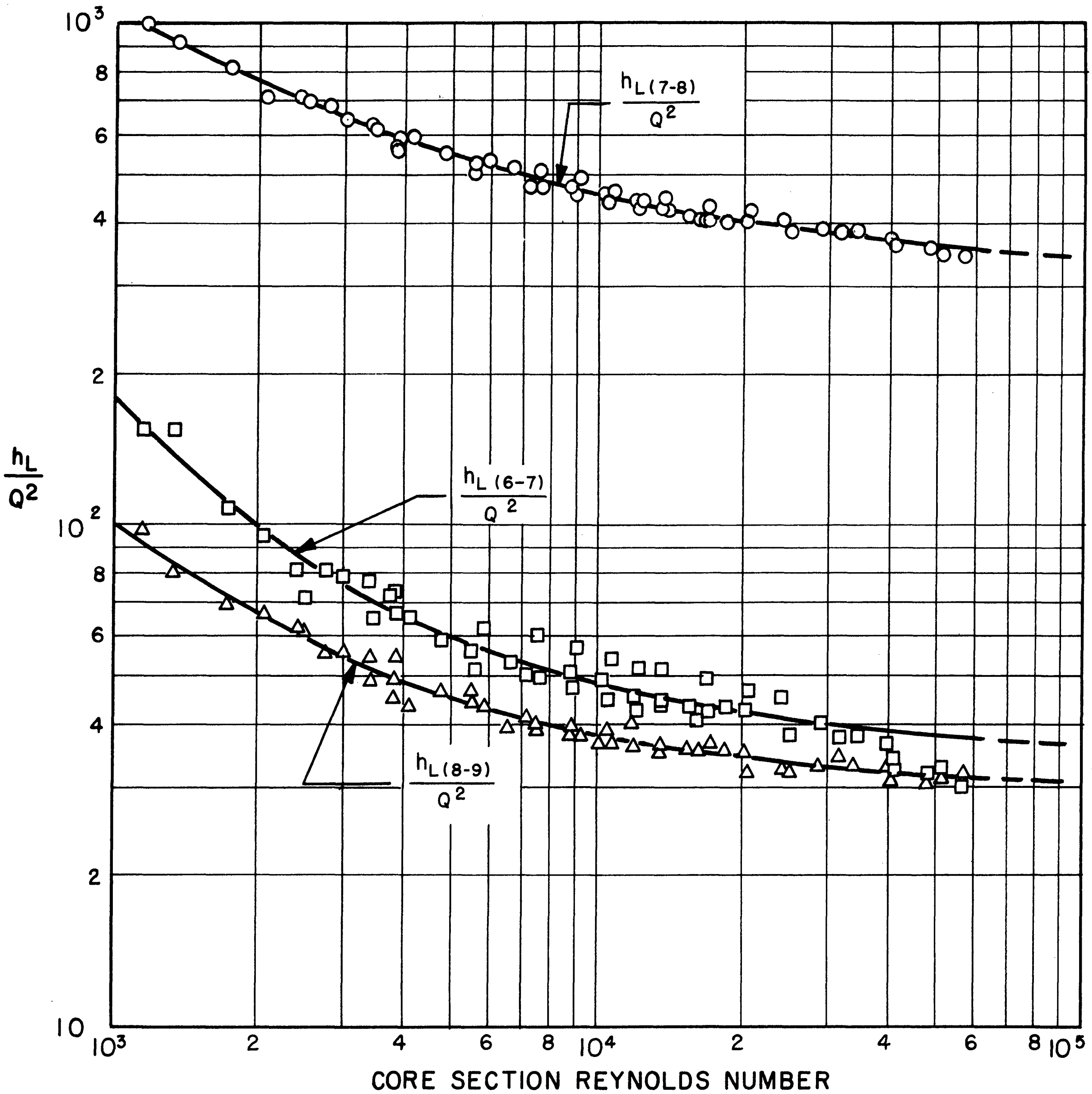


Fig. 5. Head lossess through parts of core subassembly "C."

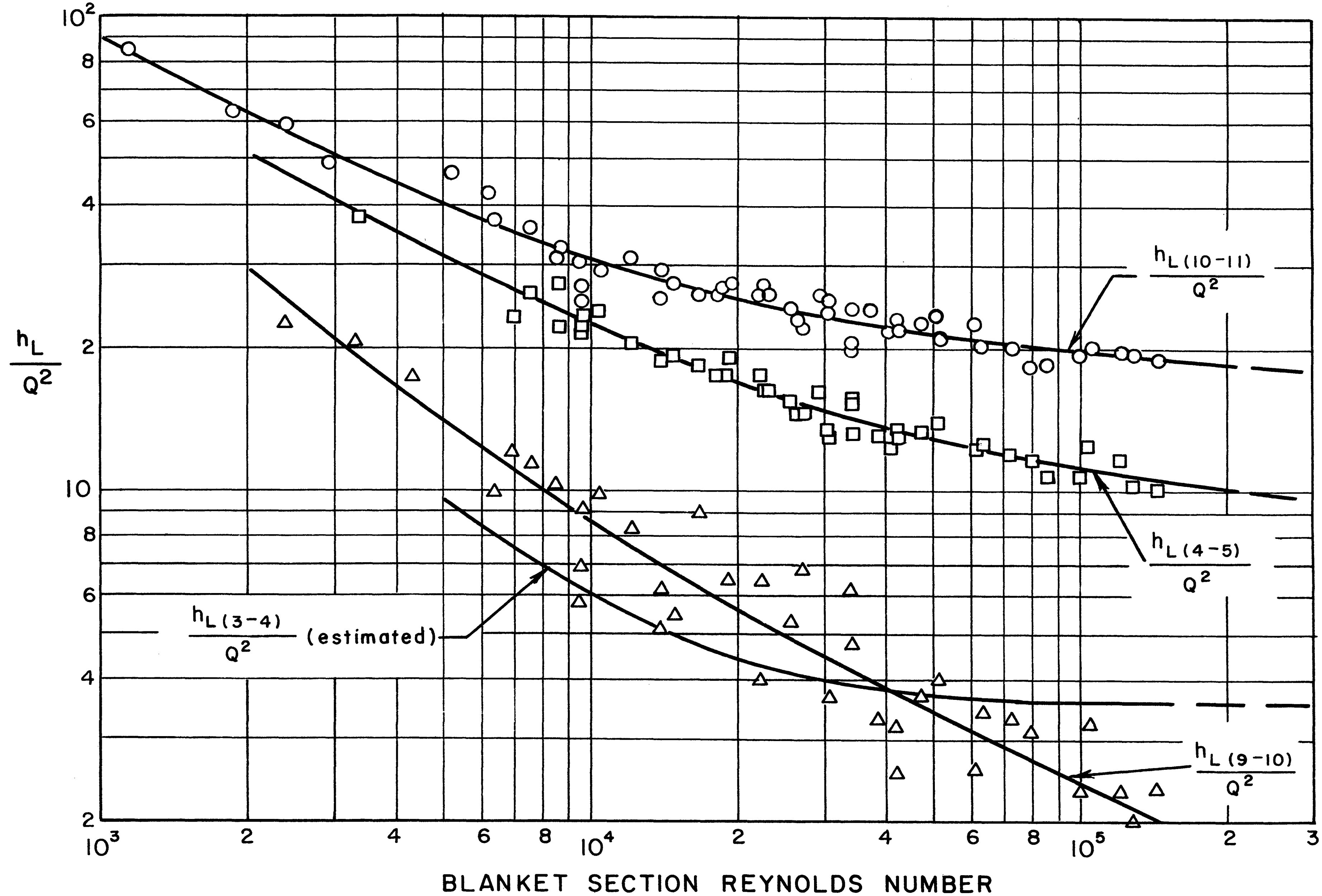


Fig. 6. Head losses through parts of core subassembly "C."

losses between piezometer openings 6 and 7, and 8 and 9 are, respectively, the entrance and exit losses of the core section.

In Fig. 7, the drop in piezometric head expressed in psi is plotted against the discharge of sodium in gpm to provide design curves based on the faired curve of Fig. 2 for the complete core subassembly. The pressure drop was converted directly from feet of sodium and it indicates the head loss for flow through the entire subassembly. The calculation of a typical point is given in the Appendix. Design points representing a discharge of 300 gpm of sodium are also shown.

C. MISCELLANEOUS TESTS

HYDRAULIC MODEL FOR SRE

In a series of laboratory tests, measurements were obtained for flow through the hydraulic model of a nuclear element to be tested in SRE. The measurements included the head loss for flow through the model without any orifice at the entrance nozzle section, and the head losses for flow with orifices of various sizes. The orifices were used as control devices to regulate the flow through the model.

The model was designed for specific tests to be conducted in an existing nuclear reactor (SRE), and in order to obtain information useful in the design of reactor elements for the Enrico Fermi Atomic Power Plant. Detailed description of the hydraulic model is given in the APDA assembly drawing No. 6XN-1698.

The core section of the model consisted of 49 rods, 0.158 in. in diameter, arranged in a square array of 7 by 7, and supported every 2 in. in each transverse direction by grids made up of 3 wires 0.066 in. in diameter; the grid wires were bent to a V-shape, with the sides of the V at 45° with the direction of the flow and pointing downstream. Four longitudinal wires, 0.047 in. in diameter, supported the grids at the corners. The calculations for the open area and equivalent diameter of a section through the core are given in the Appendix.

The entrance nozzle, the core section, and the expansion cylinder with the thermocouple guide constituted the entire model which was enclosed in a 2.81-in.-ID pipe 10 ft long. At the upstream end of the entrance nozzle section a shoulder was provided against which the orifice plates could be placed and secured in position. Two piezometer openings were made in the side of the pipe, one located 6 in. upstream from the entrance nozzle and the other 8 in. downstream from the end of the model, in a completely unobstructed pipe area. These openings were connected to a differential manometer and in this way the head loss across the entire model was determined.

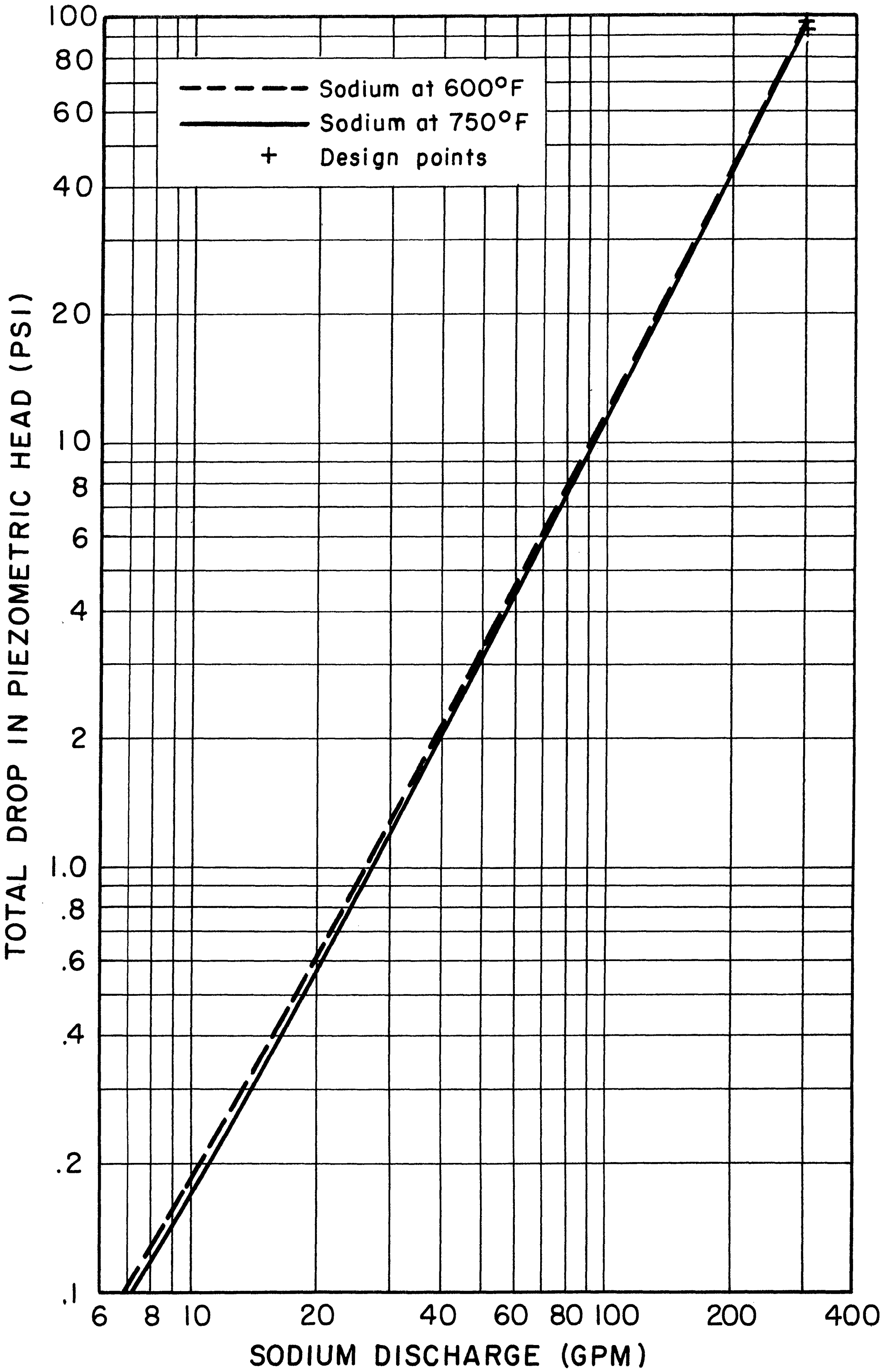


Fig. 7. Drop in piezometric head for complete core subassembly "C."

In Fig. 8, the head loss for the entire hydraulic model is expressed by the quantity $\Delta h/Q^2$, in which Δh is the drop in piezometric head and Q the discharge. The core section Reynolds number was computed on the basis of the open area and equivalent diameter of a section through the core rods. The part of the cross-sectional area extending between the square rod enclosure and the 3-in. pipe was not included in the computations given in the Appendix because this space was filled with stagnant water. In the case of flow without an orifice, the flow entered directly from the 2.81-in.-ID connecting pipe to the 1.438-in.-diameter entrance nozzle. As expected, the head loss for the entire model, and with an orifice at the entrance nozzle, increased rapidly as the orifice diameter was decreased.

In Fig. 9, the head loss for the core section only is compared with that for the entire model without an orifice. To obtain the measurements for the core section, the entire model was removed from the 2.81-in.-diameter pipe. Two piezometer openings were made in the square enclosure of the core section, one was located 6 in. upstream from the entrance to the core and the other approximately 2 in. downstream from the end of the core. The distance between the openings was approximately 40.7 in. The relatively low head losses for the entrance nozzle and expansion cylinder sections are due to the absence of axial blanket sections from this model.

In Fig. 10 the drop in piezometric head expressed in psi is plotted against the discharge of sodium in lb per hr to provide design curves for the selection of the proper size of orifice for the control of flow through the model. These curves are based on the faired curves of Fig. 8, and the calculation of a typical point is given in the Appendix.

DIVISION OF FLOW IN CORE SECTION

Special tests were run to determine the proportion of the total discharge flowing in the annular space between the container and the inner envelope of the core section (Hydraulic Model No. 4). The additional measurements made in these tests supplement those reported previously.[3]

The width of the annular space was maintained uniform along the entire length of the core with spiral windings. These spacers were of the "Modification No. A" type consisting of U-shaped strips with one side of U spot welded on the outside surface of the inner envelope. A detailed description of this type of spacer is given in the APDA drawing No. 6XN-1177.

The percentage of the total discharge which flowed outside the inner envelope versus the Reynolds number of the core section is plotted in Fig. 11 for three spiral angles of the spacers. This Reynolds number is based on the open area and equivalent diameter of the entire cross section of Hydraulic Model No. 4.[3] The variation in the ratio for small Reynolds numbers is probably caused by the change from laminar to turbulent flow.

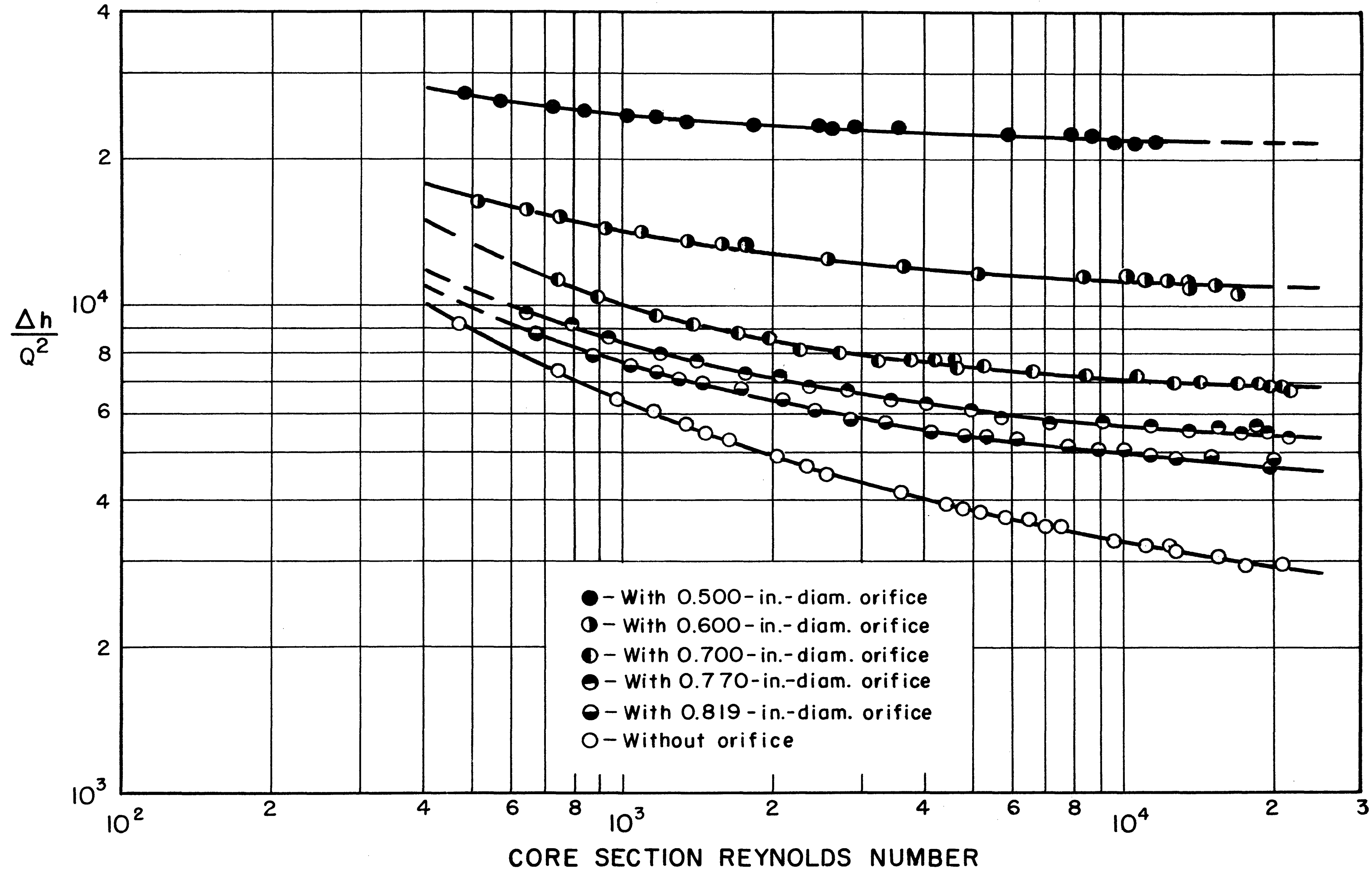


Fig. 8. Head loss for entire length of hydraulic model for SRE.

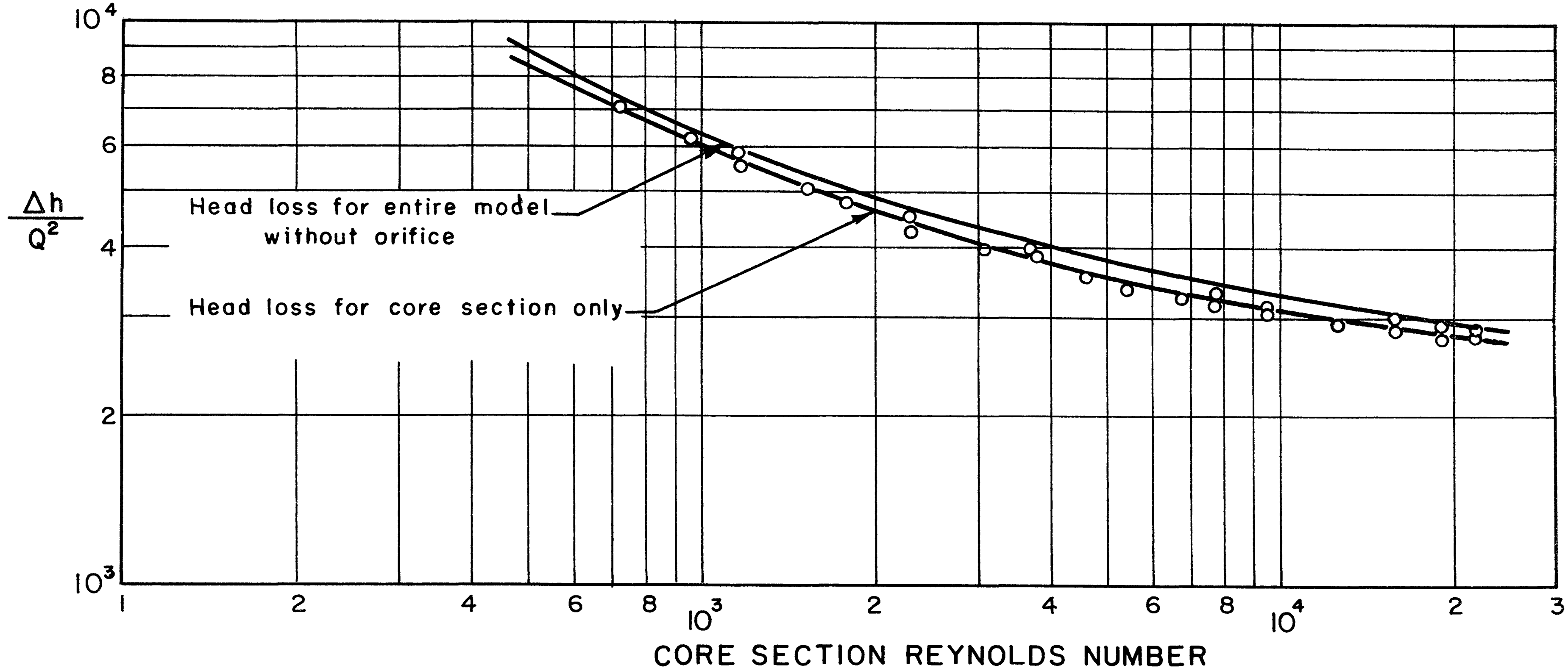


Fig. 9. Head loss for core section of hydraulic model for SRE.

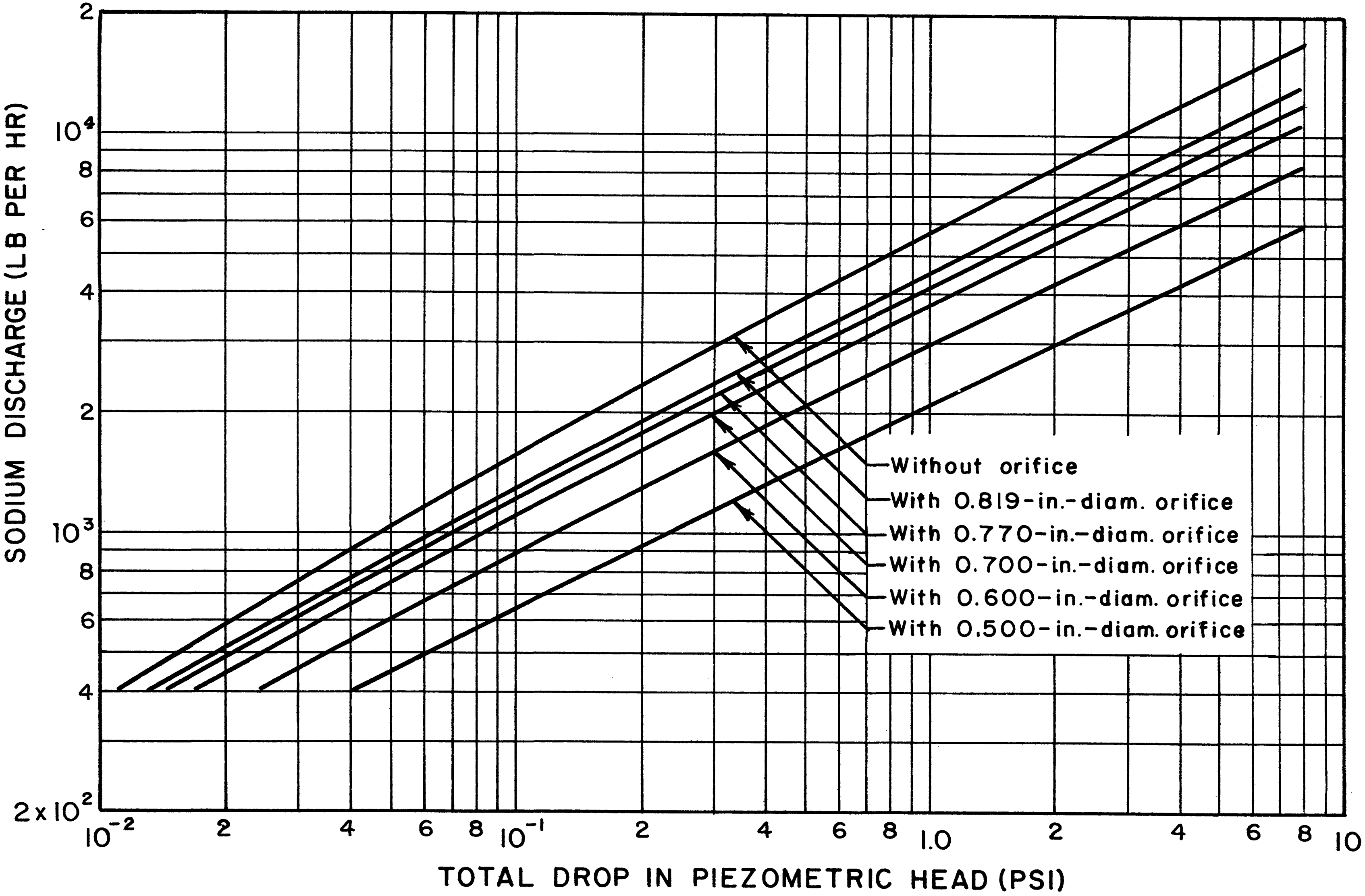


Fig. 10. Drop in piezometric head for entire length of hydraulic model for SRE (sodium at 700°F).

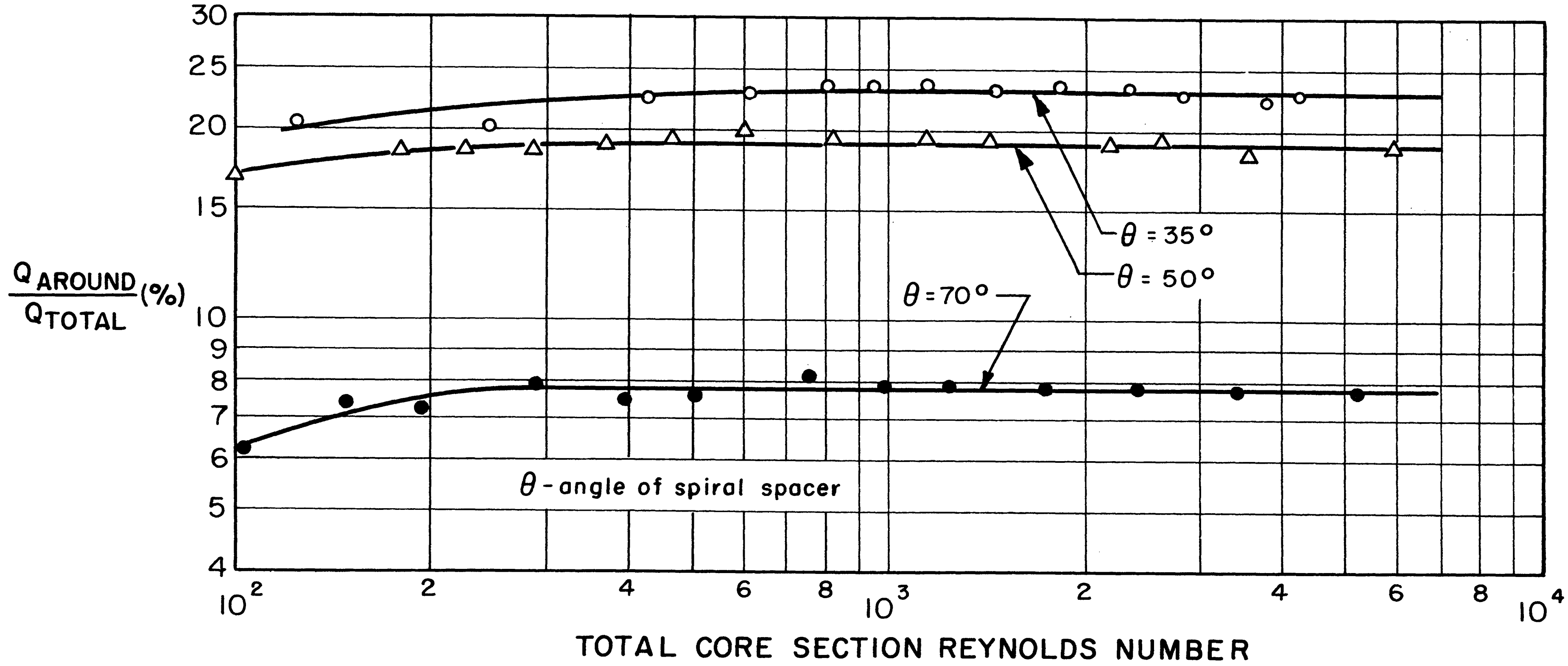


Fig. 11. Division of flow in core section, Hydraulic Model No. 4

Since there is no variation in the discharge ratio for Reynolds numbers above 1000, the test results were replotted in Fig. 12. The curve through the experimental points was extended to include the cases for $\Theta = 0°$, i.e., with the spacers parallel to the axis of the core, and for $\Theta = 90°$, i.e., with the spacers at 90° with the core axis and completely blocking the flow through the annular space. For the case of $\Theta = 0°$, the value of 25.5% was estimated from previous[3] experimental data for the pressure drop in the core section, Hydraulic Model No. 4.

HEAD LOSS WITH SPIRAL SPRING SPACERS

Tests were conducted to determine the feasibility of using spiral springs to keep the core-section rods evenly spaced and uniformly supported. The grid supports of Hydraulic Model No. 5 core section, described in a previous report,[3] were replaced by 121 spiral springs extending the entire length of the rods and occupying the space between them.

The springs were made of stainless-steel wire 0.010 in. in diameter; the outside diameter of the spring coils was 0.129 in., and the spiral pitch, 0.3 in. Springs were not used in the space between the case wall and the core rods. Instead, a cage was built inside which the springs and the rods were assembled; the cage was fastened to the anchoring frame of the rods. In Plate I photographs are shown of the core rods and springs partially assembled. To handle the springs, it was found necessary to support them by 0.095-in.-diameter wires which were slid out of the core after completion of the assembling process.

Considerable difficulty was encountered in trying to maintain a stable arrangement of the 12-by-12 array of core rods and 11-by-11 array of spring coils. With the slight dislocation of one of the rods, usually one of those located at the periphery, the whole array seemed to be affected; several rods came into contact, and several springs overlapped into each other getting entangled over considerable part of their length. To overcome this, it was found necessary to supplement the springs with two sets of grid type of supports, one at the middle and the other at the downstream end of the core. At each location the horizontal and vertical wires of the grids were at two different planes parallel to each other and 2 in. apart. At the upstream end, the anchoring bars of the rods provided the necessary support and kept the rods in position.

The combination of springs and minimum number of grid supports resulted in a stable arrangement of the rod array. The springs were secured against longitudinal motion, resulting from the drag exerted by the flow, by hooking them over the anchoring bars of the rods at the upstream end; restraint against longitudinal extension of the springs, resulting from the same type of drag, was provided by the grid wires. These wires were placed in position after the rods and springs were assembled.

In Fig. 13 the drop in piezometric head per foot of length of the spring supported core rods, divided by the square of the discharge is plotted against

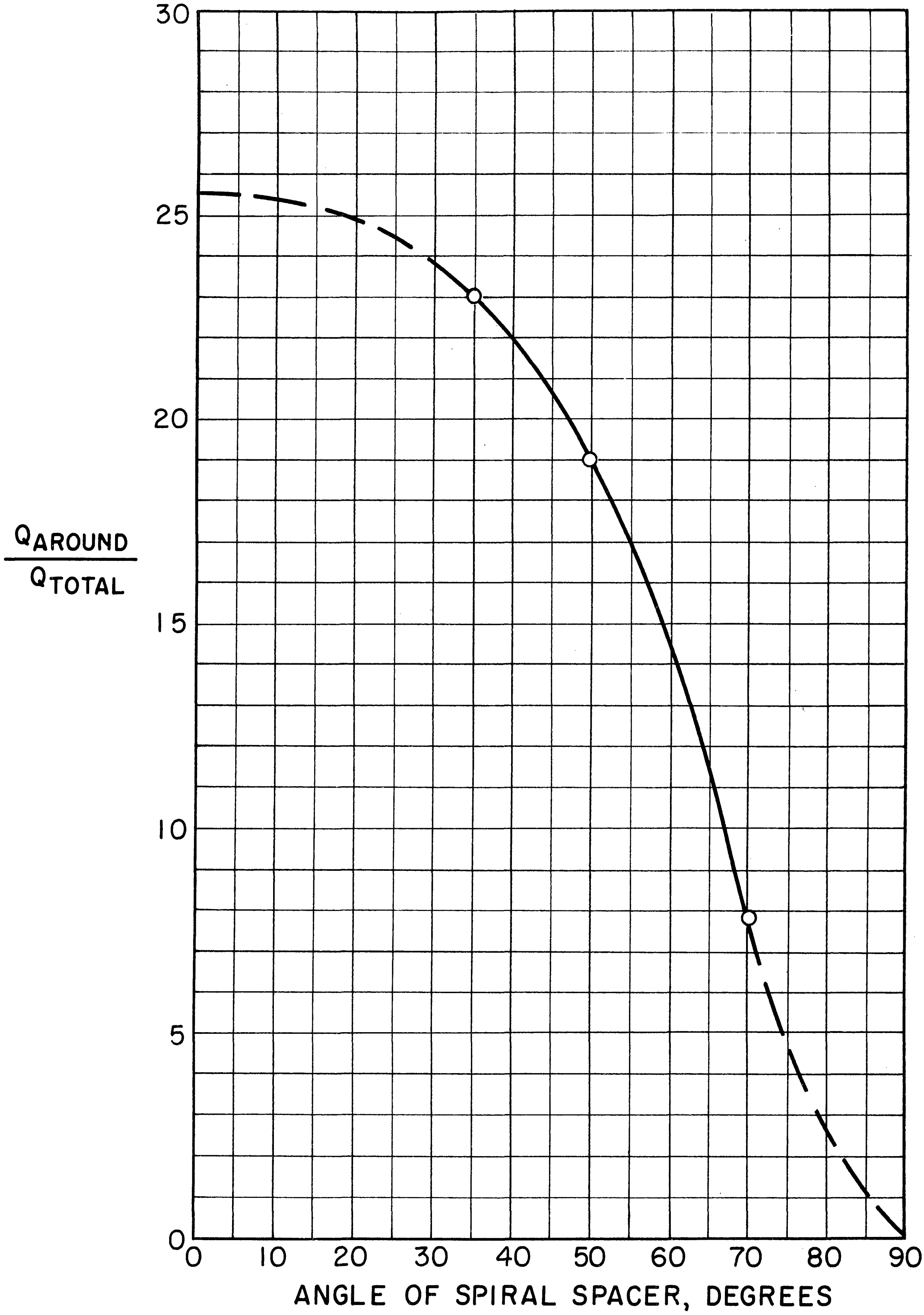
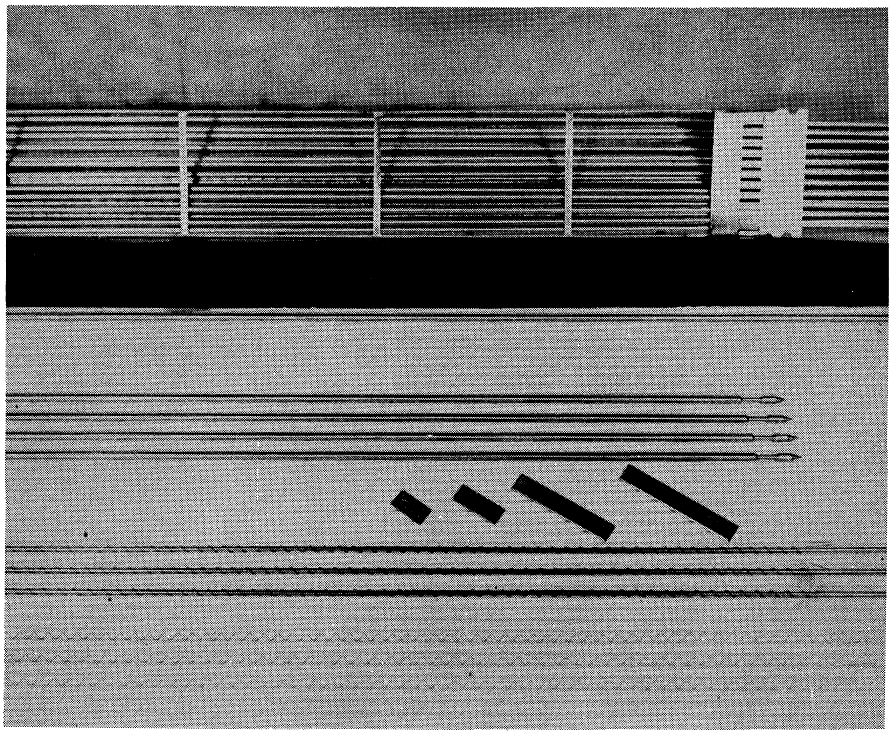
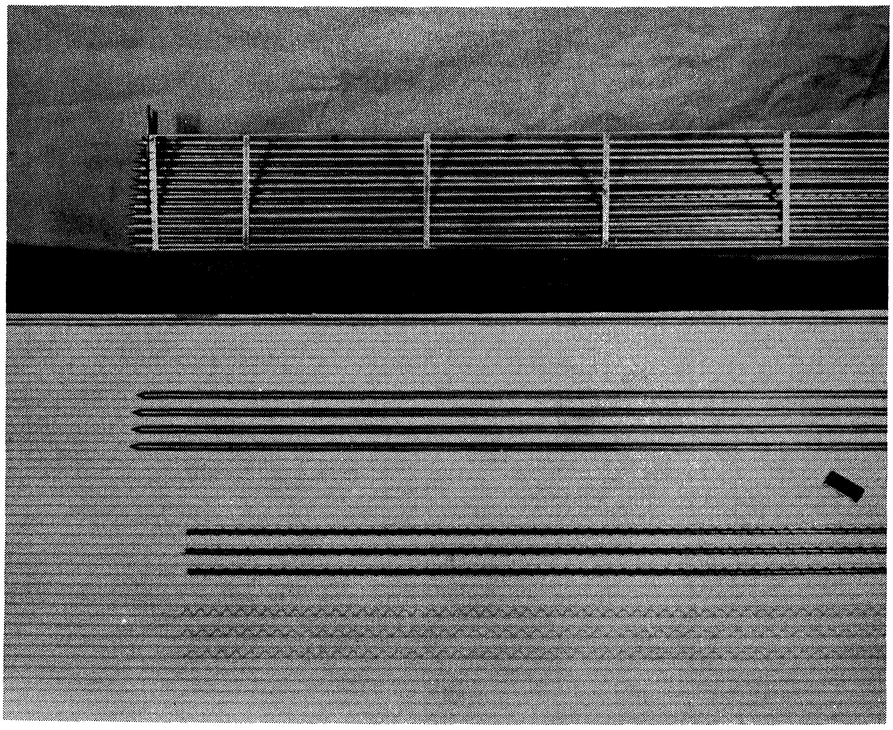


Fig. 12. Division of flow in Hydraulic Model No. 4 (for Reynolds numbers above 1000).



(a) Upstream half



(b) Downstream half

Plate I. Core rods and spring spacers partially assembled.

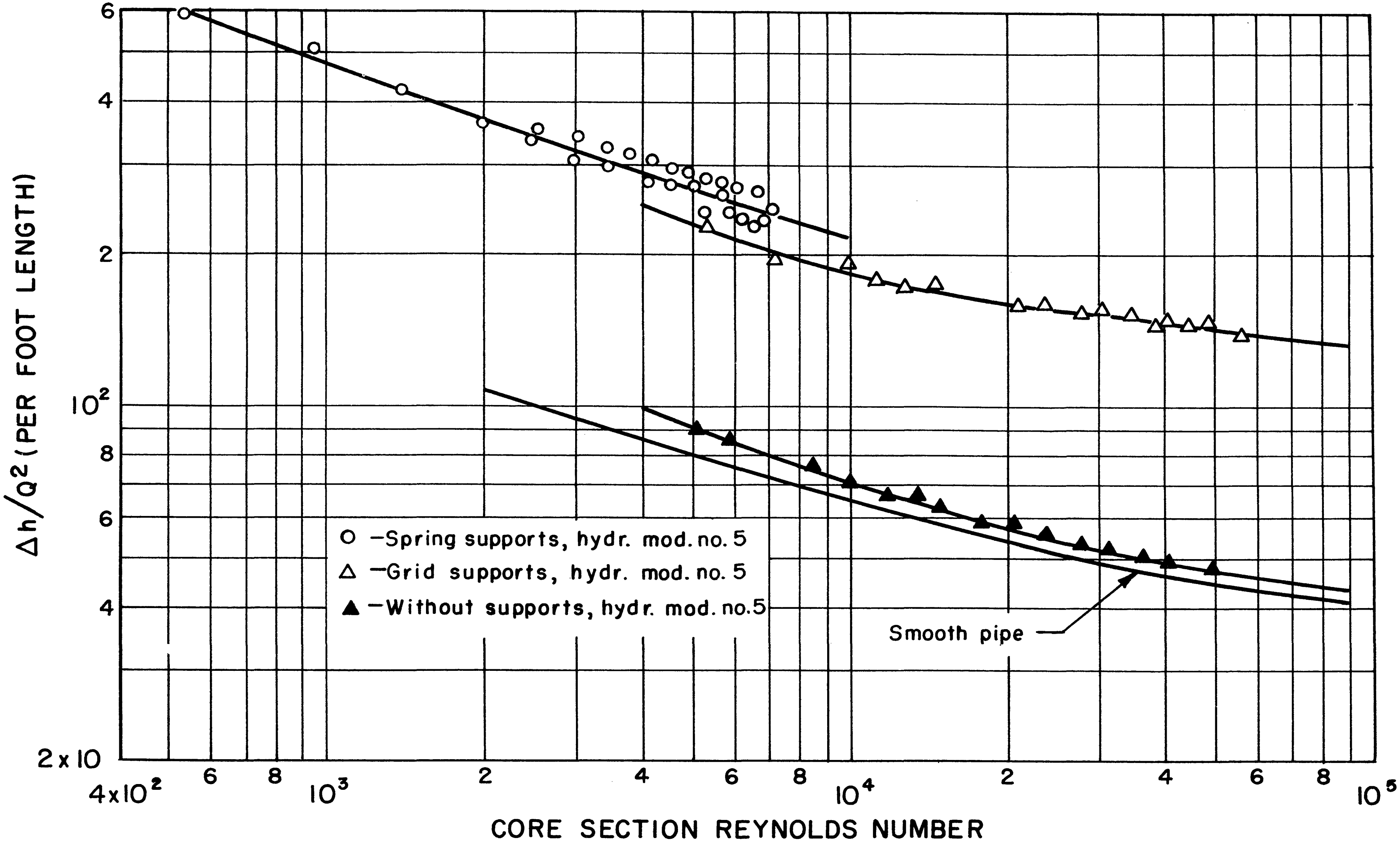


Fig. 13. Drop in piezometric head per foot of length in core section with spiral spring spacers.

the core section Reynolds number; the calculation of the open area and equivalent diameter of the core section, on which this number is based, is given in the Appendix. The measurement of the head loss was made along a section of the core which had only spring spacers. This section was located immediately downstream from the anchoring frame and just upstream of the grid support at the middle of the core. The relatively large scatter of the experimental points for the spring supported rod section can be attributed to the frequent deposition on the spring coils of small pipe scale carried by the water of the recirculating system of the laboratory; this scale was removed from the springs at the end of every run.

For comparison, the head loss for the Hydraulic Model No. 5 core section, with grid type of supports, are shown in the same figure. Also, the head losses without any supports, and for flow in a smooth pipe of an equivalent diameter, are included in the same plot.

The higher head loss associated with the use of spiral spring spacers when compared with the head loss for the grid type of supports, and the difficulties encountered in assembling a core section with spring spacers, make the use of such type of spacers impractical, and discouraged continuation of the tests.

HEAD LOSSES IN NOZZLE AND LOWER BLANKET

The appreciable reduction of head losses by streamlining the axial blanket subassembly has been demonstrated with the measurements presented in Fig. 4 of the previously published third progress report.[3] To determine proportionately the reduction of the head losses due to the streamlining of the entrance nozzle and that due to the streamlining of the lower blanket section of the second axial blanket subassembly, additional tests were conducted.

The unavailability of a uniform flow section between the nozzle and the lower blanket made impossible the separate and direct measurement of the drop in piezometric head in the nozzle and blanket of the two models. Instead, four different combinations of the first (nonstreamlined) and second (streamlined) models were tested.

The results of the tests are presented in Fig. 14. The drop in piezometric head from piezometric opening 1 to 6 (across the nozzle and lower blanket section), divided by the square of the discharge, is plotted against a Reynolds number based on the cross section of the axial blanket. First nozzle and first blanket refer to the first design, for which no effort was made to streamline the subassembly, while second nozzle and second blanket refer to the streamlined second design of the subassembly.

It is clearly seen from this plot that by far most of the reduction in head losses resulted from the streamlining of the blanket section.

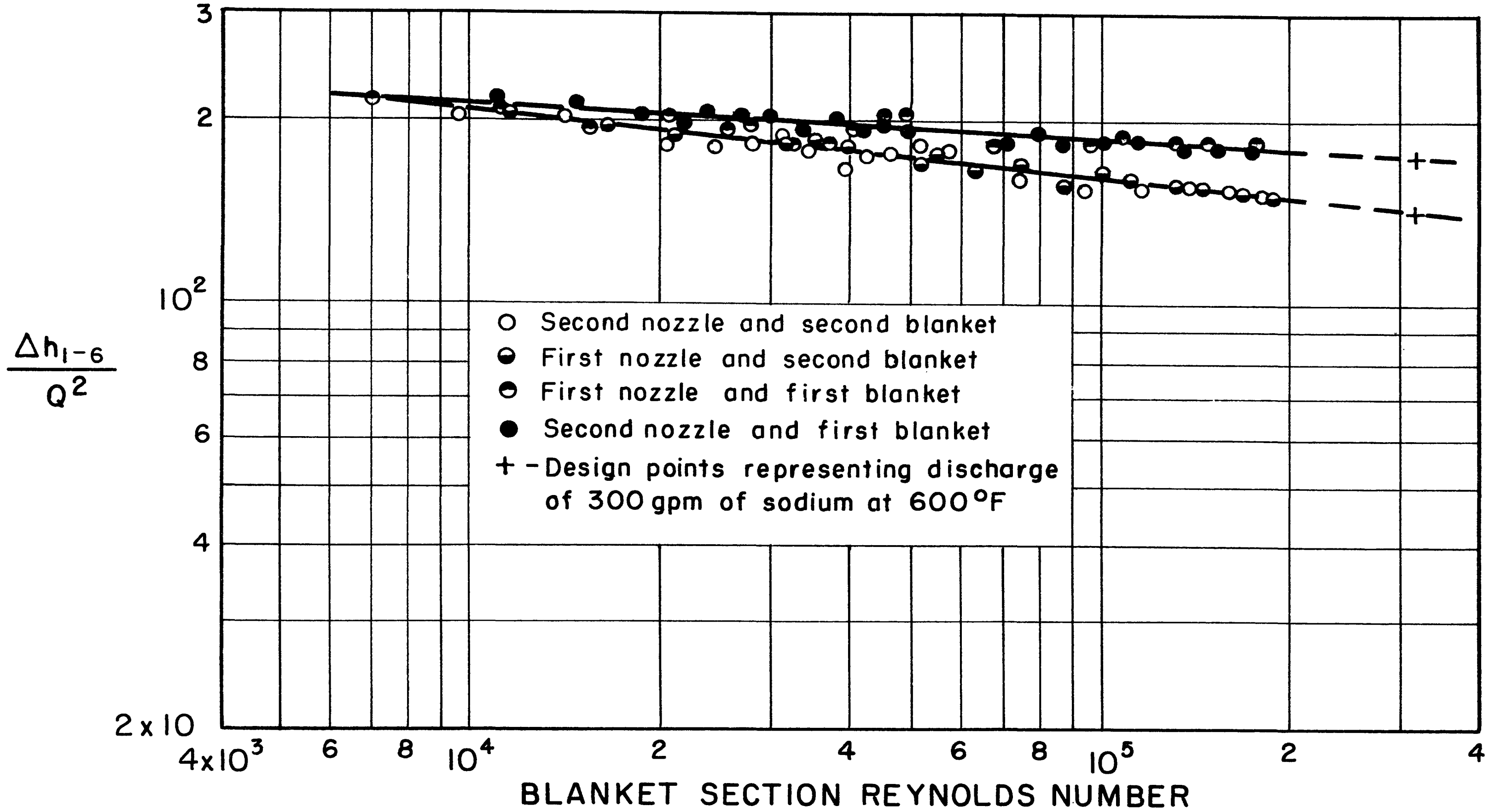


Fig. 14. Drop in piezometric head for nozzle and lower blanket combinations of first and second axial blanket subassembly.

HEAD LOSSES FOR DISTRIBUTING ORIFICES

The head losses for flow through two distributing orifices of the outer radial blanket were determined in a series of tests. The "Hydraulic Test facility for Radial Blanket Orifices," shown in the APDA drawing No. 6XN-2192, was used in the experiments to mount the two orifice plates. Briefly, this facility consisted of a horizontal conduit 27 in. long with a square flow area of 2.69 in. by 0.88 in. The conduit represented a section of the lower plenum of a reactor vessel. At one end of the conduit, a pair of nozzle sections of the outer radial blanket subassemblies were attached at right angles with the longitudinal axis of the conduit. At the other end a pipe was attached, again at right angles with the conduit but pointing in the opposite direction to that of the nozzles. The pipe was the flow entrance section of the facility and it was connected to the laboratory test circuit. A sketch of the facility is shown in the definition insert of Fig. 15.

The entrances to the two nozzle sections were fitted with special attachments for mounting the orifice plates flush with the top side of the conduit. Several pairs of orifices of various sizes were tested. Three piezometer openings, one located on the conduit and approximately 2.5 in. upstream from the center line of the inner nozzle, and the other two located on the nozzles and approximately 20 in. from the conduit, were used to measure the drop in piezometric head across the orifices. Thus, the loss for the 90° turn in the direction of flow in the approach region to the orifices, and the loss for a section of the nozzle, were included in the measurements.

The results of the tests are shown in Figs. 15 and 16. The loss coefficient K_o is defined in the conventional manner,

$$h_L = K_o \frac{V_o^2}{2g} ,$$

in which h_L is the head loss across the orifice obtained from Bernoulli's equation written between the two piezometer openings (including losses due to the approach region). The velocity V_o was obtained by dividing the discharge through the orifice by the orifice area. The Reynolds number was based on the orifice diameter, the kinematic viscosity of the water at the time of testing, and the velocity V_o.

In Fig. 15 K_o is for orifices mounted on the inner nozzle only (see definition sketch in the same figure); the outer nozzle was without any orifices with the flow entering into it unobstructed. The Reynolds number in this figure is based on the flow through the inner nozzle.

In Fig. 16 the loss coefficients were determined with orifices in both nozzles. For instance, in case (a) K_o is for the outer nozzle orifice with 0.375-in.-diameter orifices in both nozzles. The K_o for the inner nozzle orifices of

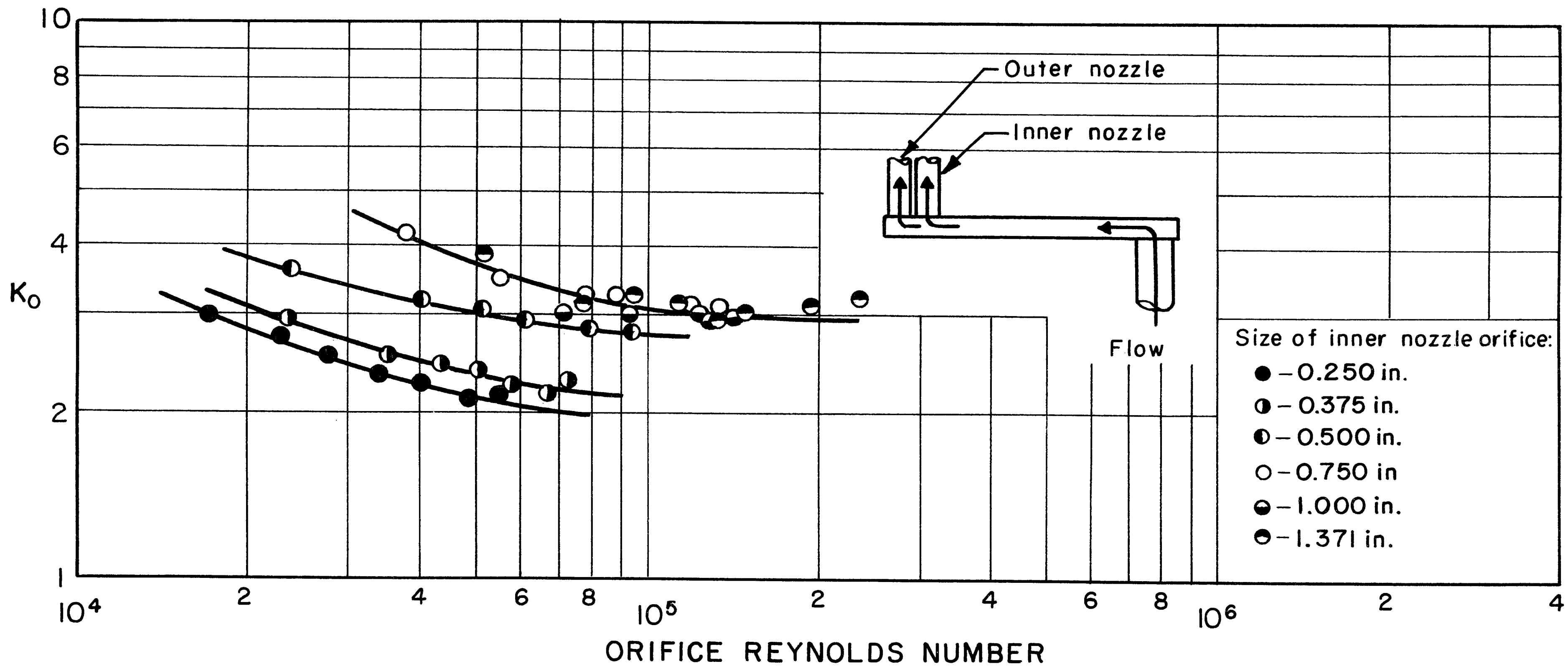


Fig. 15. Head loss coefficients for orifices in inner nozzle, outer nozzle without orifice.

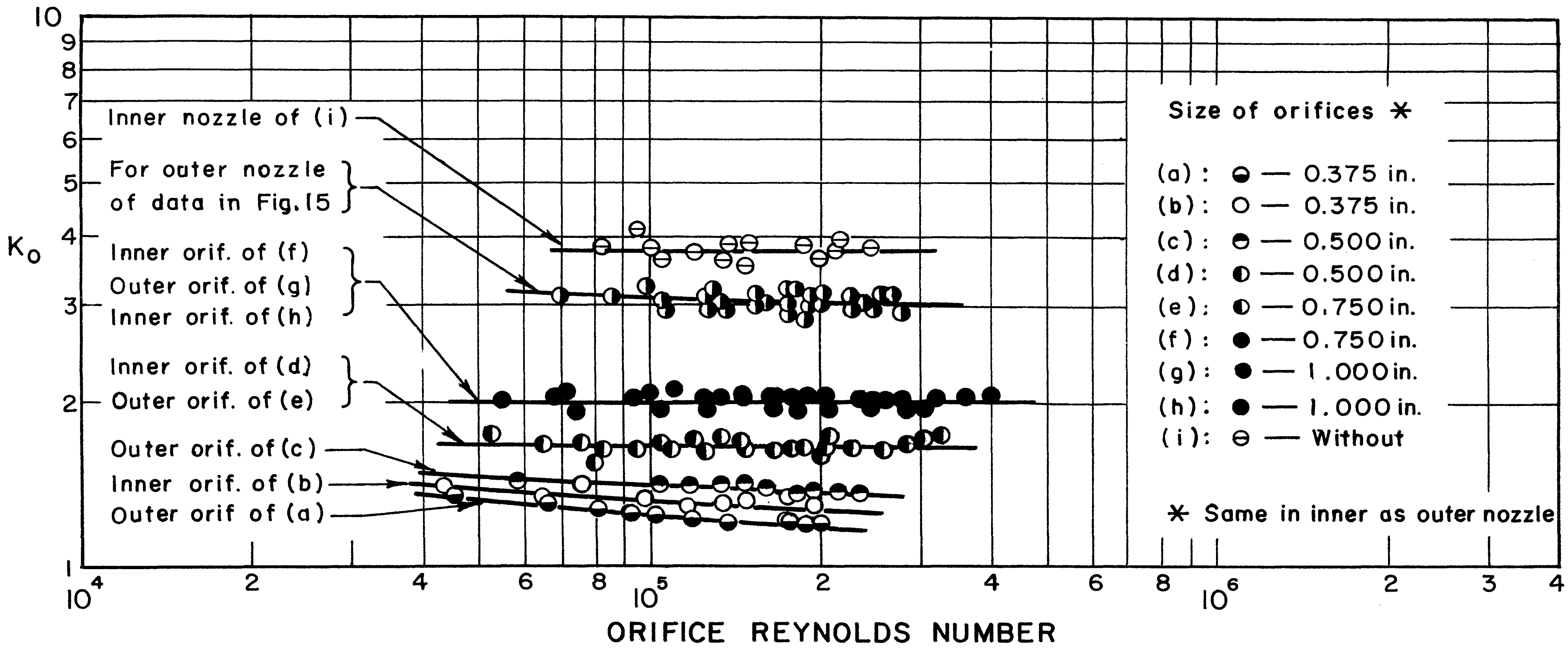


Fig. 16. Head loss coefficients for orifices in inner and outer nozzles.

the same diameter is indicated as case (b). The loss coefficient for flow through the outer nozzle without an orifice and with the inner nozzle having orifices of the same sizes as those in Fig. 15 are also shown in Fig. 16. The Reynolds numbers in Fig. 16 are based on the flow through the particular orifice for which the K_o has been determined.

ACKNOWLEDGMENTS

The experimental investigations presented in this report were carried out under the supervision of Professor Russell A. Dodge, Chairman of the Department of Engineering Mechanics. Mr. Alvin J. Engerer, research assistant, helped with the collection of data, construction and assembly of equipment, and the computations in the analysis of the results. Milo Kaufman, senior technician, and William Huizenga, technician, assisted in all phases of the laboratory work. The writer would like to thank these gentlemen for their help and support in carrying out this investigation.

The study of flow through elements of a nuclear reactor was started by Professor John S. McNown and it was supervised by him until his departure from the faculty of the University.

APPENDIX

CALCULATION OF HYDRAULIC DIMENSIONS

The open-area and equivalent diameter values used in computing Reynolds numbers are given below; these values are calculated on the basis of dimensions given in drawings of the respective models tested.

(1) Core subassembly "C":

(a) Core section (APDA drawing 6XN-1751, section B-B):

Open area:	2.454 in. square less 144 rods 0.158 in. in diameter less 4 longitudinal wires 0.047 in. in diameter or 3.18 sq in. or 0.022 sq ft
Wetted perimeter:	4 sides of 2.454 in. plus 144 rods of $\pi(0.158)$-in. circumference plus 4 wires of $\pi(0.047)$-in. circumference or 81.9 in. or 6.82 ft
Equivalent diameter:	four times open area of 0.022 sq ft divided by wetted perimeter of 6.82 ft or 0.0129 ft

(b) Blanket section (APDA drawing 6XN-1751, section D-D):

Open area:	2.454 in. square less 16 rods 0.443 in. in diameter less 4 longitudinal wires 0.072 in. in diameter or 3.54 sq in. or 0.0246 sq ft
Wetted perimeter:	4 sides of 2.454 in. plus 16 rods of $\pi(0.443)$-in. circumference plus 4 wires of $\pi(0.072)$-in. circumference or 33.0 in. or 2.75 ft
Equivalent diameter:	four times open area of 0.0246 sq ft divided by wetted perimeter of 2.75 ft or 0.0358 ft

(2) Hydraulic model for SRE:

Core section (APDA drawing 6XN-1698, section E-E):

Open area:	1.646 in. square less 49 rods 0.158 in. in diameter less 4 longitudinal wires 0.047 in. in diameter or 1.74 sq in. or 0.0121 sq ft

Wetted perimeter: 4 sides of 1.646 in.
plus 49 rods of $\pi(0.158)$-in. circumference
plus 4 wires of $\pi(0.047)$-in. circumference
or 31.47 in. or 2.62 ft

Equivalent diameter: four times open area of 0.0121 sq ft
divided by wetted perimeter of 2.62 ft
or 0.0185 ft

(3) Spiral spring spacers:
Core section:
Open area: 2.492 in. square
less 144 rods 0.157 in. in diameter
less 4 longitudinal wires 0.095 in. in diameter
less 121 spring wires 0.010 in. in diameter
or 3.376 sq in. or 0.0234 sq ft

Wetted Perimeter: 4 sides of 2.492 in.
plus 144 rods of $\pi(0.157)$-in. circumference
plus 4 rods of $\pi(0.095)$-in. circumference
plus 121 spring wires of $\pi(0.010)$-in. circumference
or 86.06 in. or 7.17 ft

Equivalent diameter: four times open area of 0.0234 sq ft
divided by wetted perimeter of 7.17 ft
or 0.0131 ft

CALCULATION OF TYPICAL POINT ON FIG. 7

The basis of the design curves presented in Fig. 7 can be explained in detail by an illustration of how a typical point was obtained. For example, the total drop in piezometric head through the entire core subassembly "C" at a discharge of 100 gpm of sodium at 600°F is 12.0 psi; the calculation for this point would be:

(1) Core section Reynolds number $= \dfrac{Vd_e}{\nu} = \dfrac{Qd_e}{A\nu} = \dfrac{(0.223)(0.0129)}{(0.022)(4.02 \times 10^{-6})} =$

$$32{,}600 \quad .$$

Total $\Delta h/Q^2$ from Fig. 2 is 638.

(2) Total $\Delta h = 638(0.223)^2 = 31.7$ ft of sodium at 600°F

(3) Drop in head in psi $= \dfrac{\gamma\Delta h}{144} = \dfrac{54.6(31.7)}{144} = 12.0 \quad .$

CALCULATION OF TYPICAL POINT ON FIG. 10

To illustrate the computations necessary to obtain the curves on Fig. 10 for the hydraulic model, the following calculations of a typical point are presented.

(1) Core section Reynolds number = $\frac{Vd_e}{\nu} = \frac{Qd_e}{A\nu}$,
in which A is the open area and d_e the equivalent diameter for the core section of the hydraulic model for SRE. The discharge in lb per hr is, then,

$$W = Q3600\gamma = \left(\frac{(\text{Reynolds Number})A\nu}{d_e}\right) 3600\gamma \quad .$$

For sodium at 700°F, $\nu = 3.61 \times 10^{-6}$ ft sq per sec and $\gamma = 53.75$ lb per cu ft, and for core section Reynolds number of 10,000:

$$W = \frac{10{,}000(0.0121)(3.61 \times 10^{-4})}{0.0185} 3600(53.75) = 4570 \text{ lb per hr} \quad .$$

(2) Total $\Delta h/Q^2$ without orifice from Fig. 8, for Reynolds number of 10,000, is 3300; from the definition of the core section Reynolds number, the discharge in cfs is

$$Q = \frac{(\text{Reynolds Number})A\nu}{d_e} \quad .$$

Therefore, total $\Delta h = 3300 \frac{(\text{Reynolds Number})^2 A^2 \nu^2}{d_e^2}$,

or, $\Delta h = 3300 \frac{(10{,}000)^2(0.0121)^2(3.61 \times 10^{-6})^2}{(0.0185)^2} = 1.84$ ft of sodium at 700°F.

(3) Drop in head in psi = $\frac{\gamma\Delta h}{144} = \frac{(53.75)1.84}{144} = 0.685$.

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