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DEPARTMENT OF THE INTERIOR

CHAMBER GEOMETRY IN MULTI-STAGE FLASH EVAPORATORS

March 3, 1849

OFFICE OF SALINE WATER

RESEARCH AND DEVELOPMENT PROGRESS REPORT NO. 108

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UNITED STATES
DEPARTMENT OF THE INTERIOR

Stewart L. Udall, Secretary

Kenneth Holum, Assistant Secretary
for Water and Power Development

SALINE WATER RESEARCH AND DEVELOPMENT PROGRESS REPORT NO. 108

CHAMBER GEOMETRY IN MULTI-STAGE FLASH EVAPORATORS

by

Richardsons Westgarth & Company, Ltd.
Wallsend-on-Tyne
England

for

OFFICE OF SALINE WATER

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July 1964

Created in 1849, the Department of the Interior--America's Department of Natural Resources--is concerned with the management, conservation, and development of the Nation's water, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department of the Interior works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States--now and in the future.

FOREWARD

This is the one hundred eighth of a series of reports designed to present accounts of progress on saline water conversion with the expectation that the exchange of such data will contribute to the long-range development of economical processes applicable to large-scale, low-cost demineralization of sea and other saline waters.

Except for minor editing, the data herein are as contained in a report submitted by the Richardsons Westgarth & Company, Ltd., under Contract No. 14-01-0001-262, which has been accepted as fulfilling the provisions of that contract. The data and conclusions given in this report are essentially those of the Contractor and are not necessarily endorsed by the Department of the Interior.

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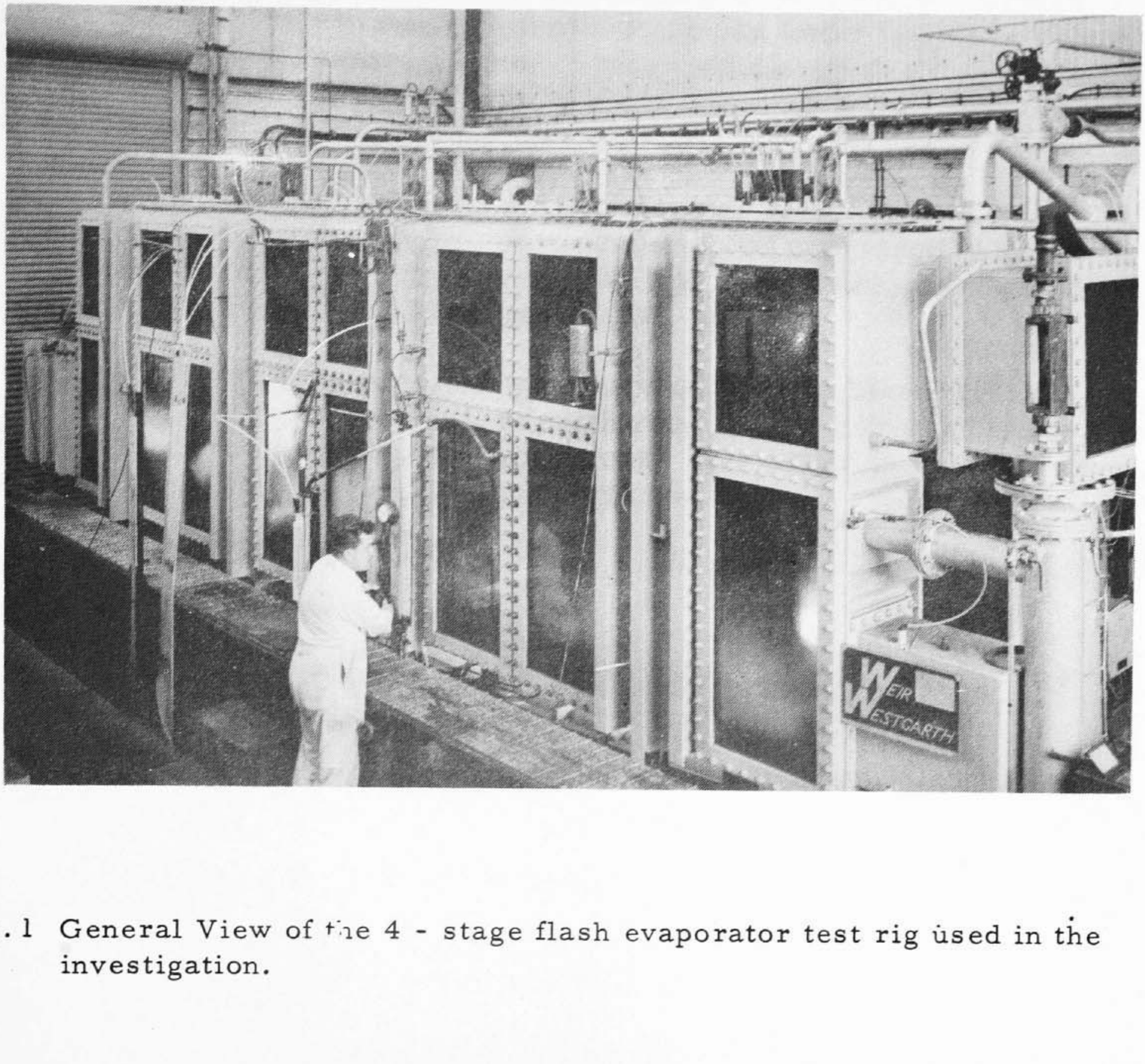


Fig. 1 General View of the 4 - stage flash evaporator test rig used in the investigation.

ABSTRACT

An investigation was made of the importance of various parameters on the length of a typical stage in a multi-stage sea water flash evaporator For a set of standard conditions, the chamber efficiency was found at different chamber sengths, and from this, an optimum length estabilished, such that vapourisation was complete.

Each parameter was examined over a range of values to determine its influence on chamber length. Data obtained was expressed in the form of curves of efficiency vs. chamber length, and from these, constant effiency curves were plotted for a given parameter.

Finally, an empirical equation was derived from the basic test data, to give an indication of the chamber length required for complete flash-off in a stage for a specified range of conditions. This eaquation was confirmed, within this range, by operation at arbitary conditions.

2. CONCLUSIONS

The following conclusions have been drawn from the investigation:-

1. If the length of a flash chamber is reduced for constant flashing conditions, the chamber efficiency remains constant at 100% until a critical point is reached. If the length is further reduced, the fall-off in efficiency is rapid for small decreases in length. (Section 5.)

2. Of all the variables studied, the brine flow has the greatest effect on the chamber length. It is apparent (Fig. 7) that changes in flow and chamber length are equivalent. (Section 8.4).

3. The chamber length is directly proportional to stage temperature drop. This variation appears to be consistent as higher temperature differences require longer chambers for complete flash-off, although the effect is not so pronounced as with brine flow. (Section 8.5).

4. It is apparent that the chamber length - temperature characteristic is a function of specific volume and is inversely proportional to temperature. (Sections 8.6 and 8.7).

5. High brine levels associated with splash plates require longer flash chambers for equilibration but small increases (up to 6") in brine level/

level above the top of the baffle plate do not appreciably increase the length required to complete flash-off. (Section 8. 8).

6. The geometry of the interstage brine transfer and splash plate arrangement is of great importance when designing a flash chamber. Long splash plates will give better protection to the vapour separator but require a longer chamber. The distance of the vertical baffle plate from the first orifice is not considered important but the baffle plate height must be taken into account. The gap between the top of the baffle plate and the splash plate is also important and, if this presents a restriction to flow, it will cause delayed flash-off and result in longer chambers. (Sections 8.9 and 8. 10).

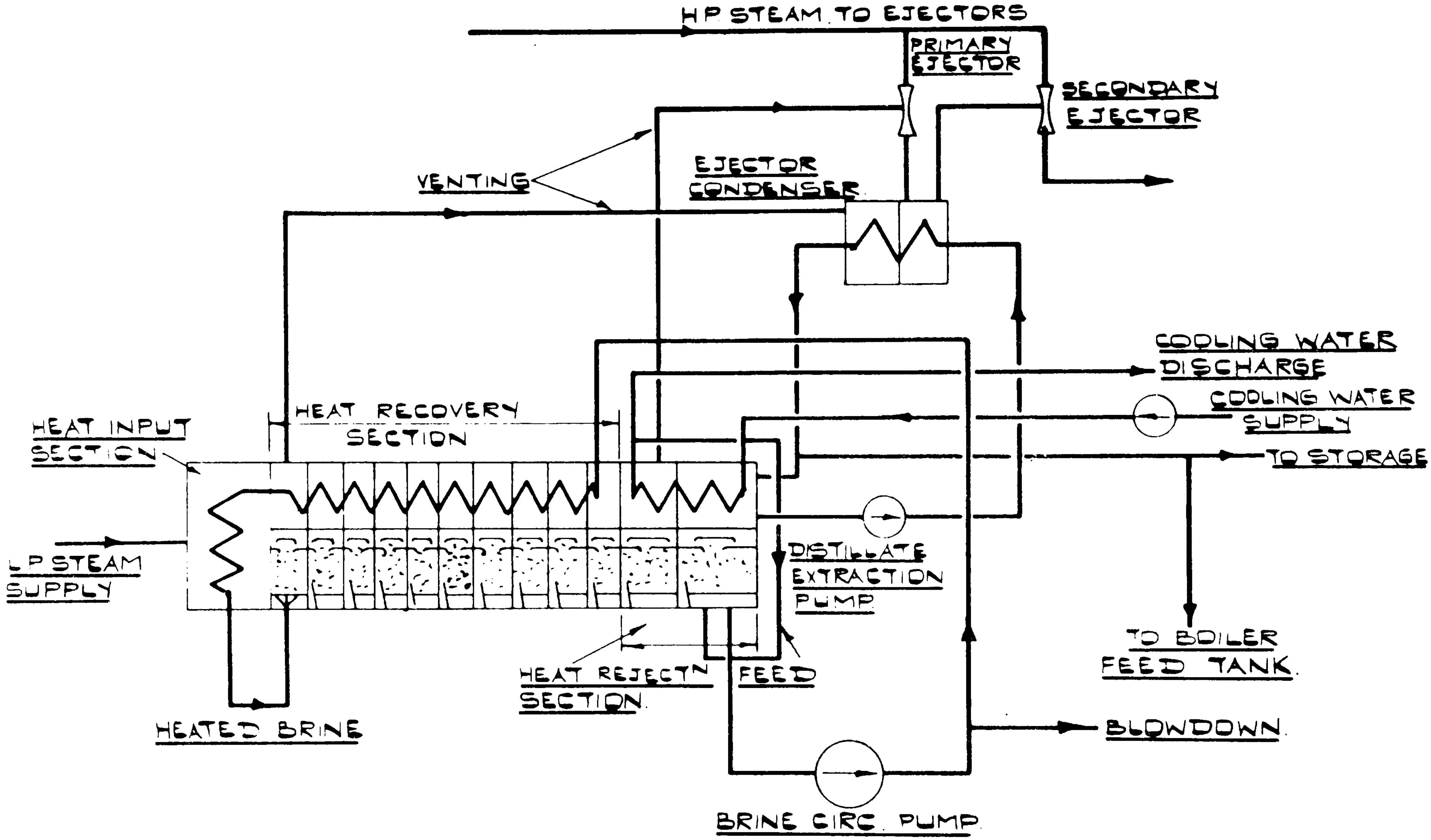
7. An empirical equation has been evolved for a specified range of conditions and will give an estimate of the minimum chamber length required for complete flash-off. (Section 10).

3. INTRODUCTION

3.1 The Flash Evaporator Cycle

At present, the cheapest practical method of extracting fresh water from sea water on a large scale is by distillation in a multi-stage flash evaporator. These evaporators operate on the principle that the amount of sensible heat which can be stored in water decreases as the water pressure drops. Thus, when hot water or brine is passed into a vessel where the pressure is sufficiently low, all the heat cannot remain in the form of sensible heat and steam must be produced. In doing so, the temperature of the brine decreases until it again reaches the saturation conditions. If the brine is then passed to a second vessel where the pressure is even lower, the same phenomenon occurs and a further quantity of steam is produced. The process is commonly called "flashing".

In a multi-stage flash evaporator (see Fig. 2), the brine is heated in the tube systems and passes from them to a series of flash chambers where vapour is produced. Brine is pumped from the sea through the heat exchanger tubes of the heat rejection section, after which a portion of it joins the brine already in the flash chambers as feed. This is pumped by the recirculating pump through the tube system associated with the heat recovery section. A large portion of the heat required to raise the temperature of the water is acquired initially in these tubes from the heat given/



EVAPORATOR PLANT FLOW DIAGRAM. FIG. 2.

given up by the condensing vapour. It receives the supplementary amount of heat necessary to bring it to its highest design temperature in the heat input section and then passes to the series of flash chambers where it flashes off as vapour. This vapour passes through moisture separators to eliminate any entrained brine droplets, condenses as distillate on the outside of the tubes and drops into the distillate tray. In doing so, it passes its latent heat to the water flowing through the tubes. All external heat supplied to the plant must ultimately be rejected from the plant. In the fresh water evaporator, this heat is given up to sea water circulated through the tube system in the heat rejection section and is afterwards rejected to waste.

It can be seen from the diagram that some of the circulating brine is rejected to waste, some of it becomes distillate and that fresh sea water is added as feed. By this means correct water levels are maintained in the evaporator vessel and the concentration of dissolved solids in the circulating brine is prevented from rising above acceptable limits.

Physically, an evaporator is a mild steel fabrication made up of a heat input section and a series of chambers which form the heat recovery and heat rejection section. These chambers each consist of a flash section, moisture separators, and condensing tubes. Detailed design depends on the output and the performance required.

3.2/

3.2 History of the Problem

The cost of the product water from an evaporator is the sum of various component costs (i.e. fuel, pump power, capital costs of shell and tubes etc.). Of these, capital expenditure on main vessel steelwork, including transportation, insurance, fitting, etc., amounts to from 20% to 35% of the total cost of the plant. Hence, to keep the cost of the plant to a minimum, the flash chambers should be as small as possible.

In the past, there has been little information available to assist designers in calculating the optimum chamber size for a given condition. Consequently, flash chambers have, in general, been designed larger than necessary for complete liquor equilibration. The main difficulty in establishing the correct chamber size can be traced to the lack of experimental data on the flow-time history of the two phase mixture across a given chamber. Thus, the mean density and velocity of the two phase mixture, at any instant, cannot be determined accurately.

Although there have been many attempts (1), (2), (3) and others, to predict the flow of two phase fluids under evaporating conditions, efforts to estimate the time required for equilibration from these data, applied to evaporator flash chambers, have not been successful. In particular, Simpson and Silver (3) evolved an approach which considered the problem basically in two parts - namely, bubble nucleation and growth. Their theory implied a time/

time factor for vapour generation but depended upon the experimental evaluation of two nucleation constants. Data presented, indicated values of the constants which were consistent at high pressures (20 p.s.i.a. and over), but agreement with practice was not good at low pressures (less than atmospheric). This tendency was evident in other theoretical approaches.

An experimental investigation was carried out by Richardsons Westgarth & Co. Ltd, Wallsend, England, (4) to determine the time for complete flash-off from a quantity of saturated water exposed to a sudden pressure drop. These experiments were only partly successful. An estimate of the time required was obtained but the conditions were dissimilar to those in an evaporator where the fluids were in motion and the pressure drop varied with time, there being a gradual pressure drop through the brine transfer arrangement. As a result, it was almost impossible to use the limited information available for the design of a flash chamber.

3.3 Purpose of Investigation

It was finally decided that the best approach to the problem was by simulation of an evaporator flash chamber. At that time, Richardsons Westgarth had a large 4-stage evaporator test plant installed at their Hartlepool Works, England, and it was this plant which was chosen as being most suitable for the experimental work.

To study the problems in chamber geometry, a secondary adjustable

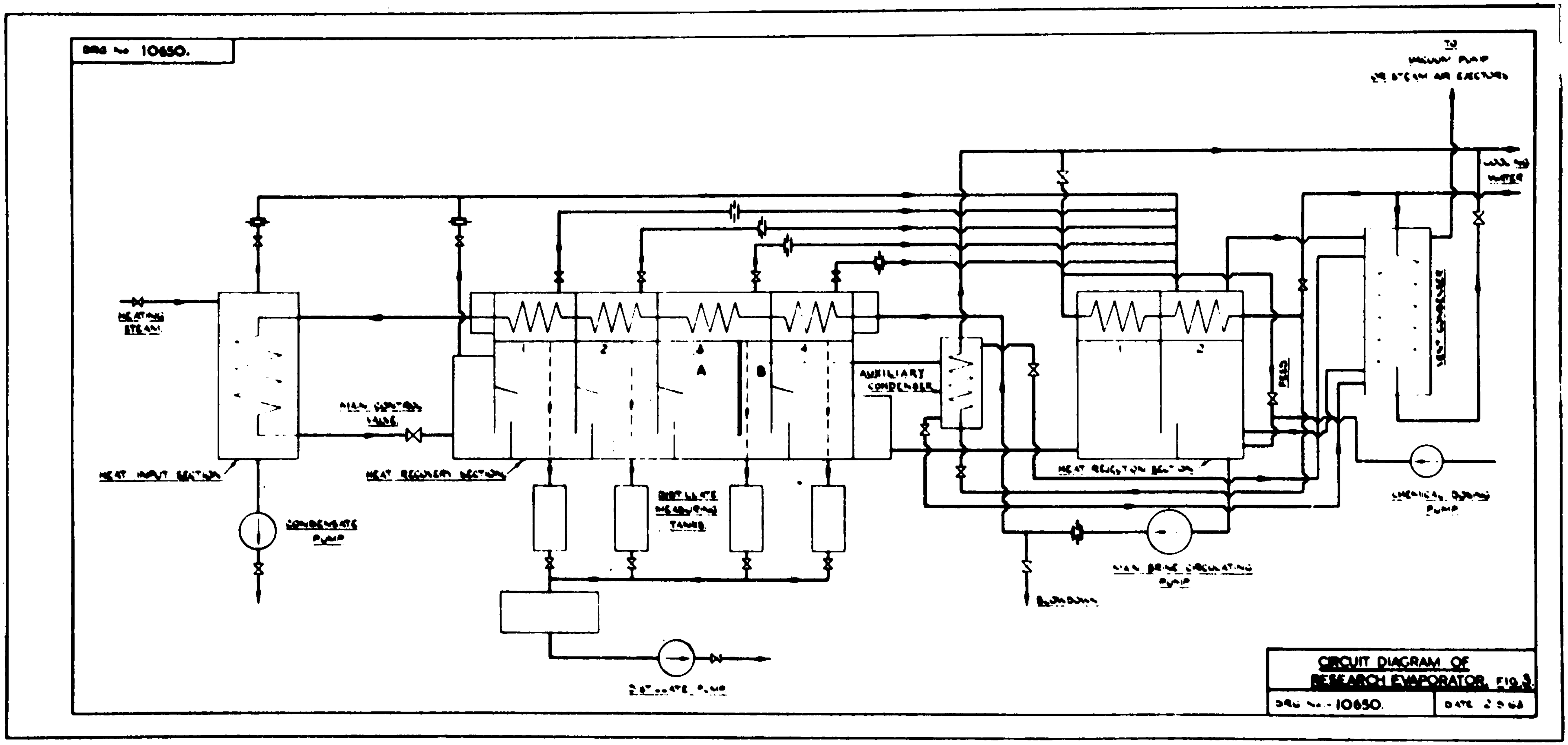
wall/

wall was fitted to one of the flash chambers, which enabled adjustments in chamber size to be made over a wide range. Different running conditions would be tested on the plant and the information obtained would cover the ranges of conditions normally met with in the larger multi-stage flash evaporators.

4. DESCRIPTION OF RESEARCH VEHICLE

The research vehicle used in the investigation (Fig. 1) allows the flashing conditions of temperature and flow of any four consecutive stages of a multi-stage sea water flash evaporator to be reproduced. It consists of a separate heat input section, a four-stage heat recovery section, and a two-stage heat rejection section. The research plant can be run as a complete evaporator, except that the small number of stages restricts the overall temperature drop to that of any four stages of a complete commercial unit. A circuit diagram of the plant is shown in Fig. 3.

The four flash chambers are each 5'9" long, 1'6" wide and 3'9" high. Provision is made for fitting two vapour/brine separators in the roof of each chamber but normally only one is necessary. The steam passes through the separators and condenses on the heat recovery tubes. The incondensible gases are vented from each stage into the heat rejection section. Distillate is drawn from each stage into measuring cylinders before being mixed and pumped either to waste or to the factory boiler feed storage tank. The distillate purity from any stage or from the mixture can be recorded on a Crockatt Salinometer and Recorder. A detailed description of the evaporator is given in Appendix 1.



CIRCUIT DIAGRAM OF RESEARCH EVAPORATOR. FIG. 3.

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5. EXPLANATION OF PRINCIPLE USED IN RESEARCH WORK

The purpose of the research work was to estimate the required flash chamber length for different conditions of brine circulation and flash-off conditions. Thus, it was obvious that the chamber length would have to be altered.

When the first part of the chamber, part A, (Fig. 4), was at its maximum length, it was assumed that complete flash-off of the brine was taking place and the brine left the chamber at the saturation temperature. However, if the wall was moved along the chamber while the plant was running at steady conditions, it was obvious that a point would be reached where complete flash-off could not be obtained due to a finite time being required for the flashing process. If complete flash-off did not take place in part A, the brine, in a superheated condition, would pass under the moveable wall into part B of the chamber where it would flash-off until it reached its saturation temperature. To ensure that vapourisation in part B would be due only to residual superheat in the brine, it was necessary to maintain equal vapour pressures in parts A and B of the chamber. Comparison was by a sensitive differential manometer connected to the vapour spaces of A and B.

For the purpose of estimating the chamber efficiency, the steam formed in part B was condensed in an auxiliary condenser. The rate of distillate production from the main part of the chamber - part A - and from the/

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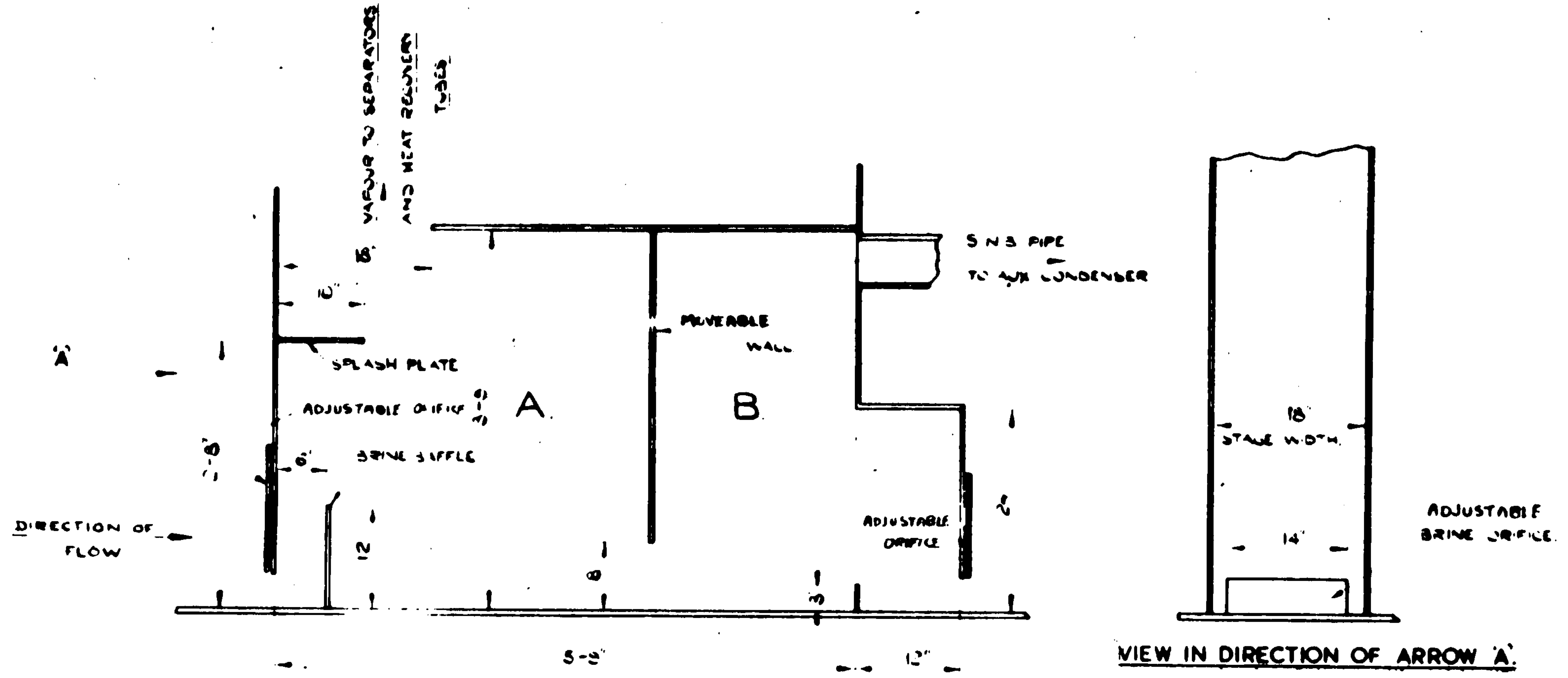

SECTIONAL ELEVATION THROUGH STAGE LENGTH.

VIEW IN DIRECTION OF ARROW 'A'.

SECTION THROUGH STAGE 3 OF RESEARCH EVAPORATOR, FIG 4.

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the auxiliary condenser - part B - was used to give an indication of the chamber efficiency. Thus,

$$\text{Chamber Efficiency } \eta_s = \frac{D_A}{D_A + D_B}$$

Where D_A = distillate production from A

D_B = " " " B

6. EXPERIMENTAL WORK

6.1 Procedure

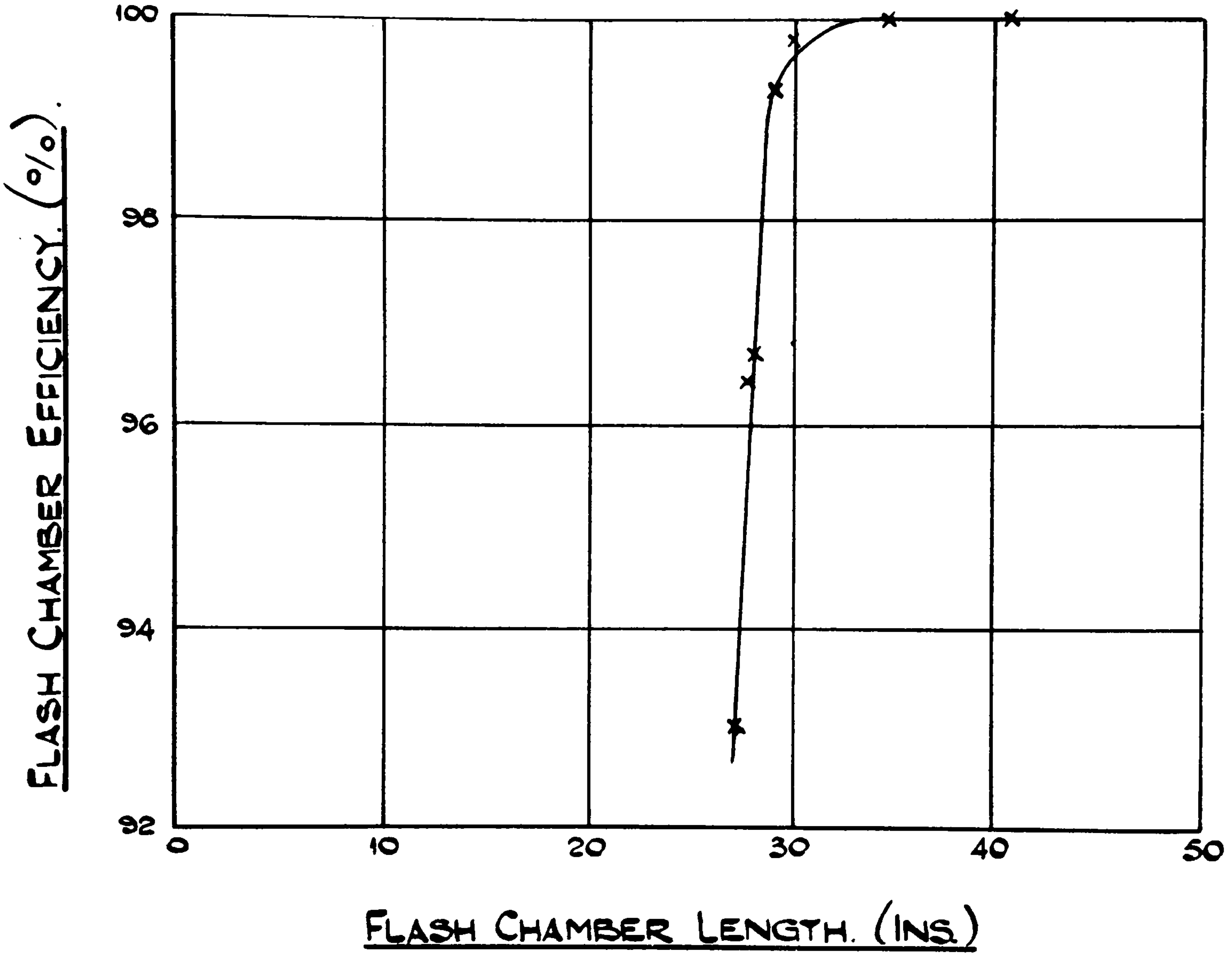
The test work consisted primarily of finding, experimentally, the minimum chamber length required for efficient operation at different running conditions. To do this, the moveable wall was traversed along the length of the chamber until it became obvious that the chamber was too small.

With steady running conditions and part A at maximum chamber length, a reading was taken of the pressure difference between A and B. The condensate level and cooling water to the auxiliary condenser were adjusted until the pressures were equal. Test readings were then taken over a period long enough to minimise any errors due to fluctuations of the distillate quantities from both sections. The chamber efficiency for that particular chamber length could then be calculated. The wall was then moved upstream several inches and the test repeated. By continuing this, a plot was obtained of the chamber efficiency against the effective chamber length.

A typical curve is shown in Fig. 5. For decreasing chamber lengths, the efficiency continues at 100% for part of the curve until the stage becomes inefficient - thereafter, the efficiency begins to drop off rapidly.

In order to restrict the number of tests to a reasonable quantity, it was decided to run the test plant at conditions in the middle of the normal flash range of a large commercial evaporator and to explore different parameters, /

TYPICAL CURVE OF EFFICIENCY AGAINST CHAMBER LENGTH. FIG: 5



BRINE TEMPERATURE ———————150° F.
ΔT/ STAGE ———————————3° F.
BRINE BAFFLE ——————————12" HIGH.
DISTANCE FROM STAGE WALL ——6"
SPLASH PLATE LENGTH ————10"
HEIGHT ABOVE CHAMBER FLOOR—27"
BRINE CIRCULATION ———————250,000 LB/HR FT WIDTH.

parameters, each could then be tackled in turn with the others fixed until a realistic range was covered. Thus, a set of standard conditions were established.

The standard test conditions chosen were:-

Stage brine temperature - 150°F

Interstage temperature drop - 3°F

Brine circulation - 250,000 - 300,000 lbs/hr foot width of chamber.

Splash plate - 10" long, horizontal and 32" above the floor of the chamber.

Baffle plate - 12" high, placed 6" from the plane of the interstage wall.

Brine level - 12" - filling chamber to the top of baffle plate.

Brine - Sea water treated with 1 p.p.m. anti-foam.

Brine concentration - 2:1.

6.2 Test Series 1, 2 and 3

See Appendix 2.

6.3 Brine Circulation : Test Series 4

To discover the importance of brine circulation on flash chamber lengths, tests were conducted with brine circulations from 200,000 to 500,000 lbs/hr. In each case, tests consisted of traversing the wall along the/

the flash chamber and measuring the stage efficiency for different lengths. The result of these traverses are shown in Fig. 6.

For the brine circulations from 200, 000 - 400, 000 lbs/hr. ft., the test conditions were kept to those shown above, but for circulations greater than 400, 000 lbs/hr. ft., it was found necessary to increase the distance between the baffle plate and the orifice from 6" to 9" and to increase the temperature at which the tests were conducted from 150°F to 180-190°F, since the pressure difference available for brine transfer was inadequate at the standard conditions of 150°F and 3°F temperature difference.

From the family of stage efficiency curves obtained, a curve of brine circulation against chamber length was drawn for the 99% efficiency point - Fig. 7. Thus, a minimum chamber length using the 99% efficiency criteria for any circulation between 200, 000 and 500, 000 lbs/hr. ft. could be found for the above temperature conditions and chamber configurations.

6.4 Interstage Temperature Drop : Test Series 5

The temperature drop per stage of an evaporator generally depends on the number of stages and the flash range for which the plant is designed. To investigate the effects on chamber length, a number of traverses of the wall were made at stage temperature drops between 1.8°F and 8°F for constant conditions of brine circulation. The results from these tests are plotted on Fig. 8, and from them, the 99% points have been taken and plotted on Fig. 9 where the temperature drop is drawn to a base of flash chamber length. /

length.

For the test at 5.7°F temperature drop, the vapour velocities within the chamber were extremely high and the distillate purity began to decrease as the chamber length was reduced. For the tests 23/5 - 25/5 (Appendix 2) at short chamber lengths, the carry-over was such that the distillate contained sufficient brine to invalidate the distillate quantity as a means of measuring the stage temperature drop accurately. Consequently, it was necessary to rely on overall plant temperature measurements as an indication of stage temperature drop. For the tests at 8°F, alterations were made to the plant to reduce the steam velocities in the separators, and although the distillate purities were poor by commercial standards, they did allow an approximate estimate of the stage temperature drop to be made.

6.5 Stage Brine Temperature : Test Series 6

In a multi-stage flash evaporator, the circulating brine may flow into the first stage of the unit at a temperature of 190-200°F and will be reduced in temperature in the succeeding stages until it leaves the last stage at 100-110°F. To investigate the chamber length necessary for complete flash-off over the range of temperature met with in an evaporator, a third series of traverses of the wall was made. The results from these tests at temperatures between 200°F and 125°F are shown in Fig. 10.

As before, the 99% efficiency points for each temperature were

plotted/

plotted on Fig. 11 and a curve was drawn through these 99% points.

6.6 Low Temperatures - 125°F to 100°F

It was found that at temperatures less than 125°F, the baffle arrangement was unsuitable and the brine level became too high in the upstream stage. To try and extend the range of conditions down to 105 - 100°F, the brine circulation was reduced from the 300,000 lbs/hr. ft. at which the other tests were conducted, to 250,000 lbs/hr. ft. and the baffle plate was moved 3" further from the first orifice, (i.e. 9" away), but the brine levels continued to be higher than for the other tests. The results of a traverse of the wall under these conditions (30/6 - 38/6) are plotted on Fig. 12 but show that a much longer chamber length than would be expected is necessary for these conditions.

Two other traverses were completed with a different baffle arrangement - a 6" high baffle plate, 12" from the first orifice for brine circulations of 250,000 and 200,000 lbs/hr. ft. (Fig. 13). These interstage brine transfer arrangements were suitable for the available interstage pressure difference but had different characteristics to the original 12" baffle, and again, the results cannot be compared directly with those between 200°F and 125°F.

6.7 Interstage Brine Transfer Arrangements : Test Series 7

To investigate the effect of changing the brine transfer arrangement, the/

the position of the 12" high baffle plate was tested at 3" and 9" from the 1st orifice at the same conditions as that for the standard 6" distance. A traverse at each position gave the results which are plotted on Fig. 14. While some change in the slope of the curves is evident, the curves appear to pass through a common point at 99% and, allowing for experimental error, it is suggested that the results are close enough to each other to assume that the distance of the baffle plate from the first orifice is not important in the determination of the chamber length.

A further test at the same conditions but with a 6" high baffle plate placed 12" from the first orifice is also plotted on Fig. 14, and indicates that the baffle height is important. In this test, the brine level was kept at 12", thus flooding the baffle by 6", and it is thought that this additional 6" head above the top of the baffle plate, (see also Test Series 8) and the reduction in turbulence are responsible for requiring the longer chamber for complete flash-off.

6.8 Brine Level : Test Series 8

For most of the test work, the brine level in the chamber was kept at 12" - at the same height as the baffle plate. To investigate the effect on chamber length of running the baffle immersed, traverses of the wall were made at 15", 18" and 22". The results are plotted in Fig. 15 and show that for higher brine levels, longer chambers are required to give complete flash-off.

6.9 Test Series 9 and 10 See Appendix 2

6.10 Splash Plate Dimensions : Test Series 11

(a) Splash Plate Height

During the early work (Series 3), the splash plate was set at 22" high, i.e. 10" above the top of the baffle plate. Tests were conducted at brine circulations from 200,000 lbs/hr.ft. to 300,000 lbs/hr.ft. but it was found that for brine circulations above 300,000, the steam/brine mixture required a very high pressure drop to enable it to flow through the brine transfer arrangement. This was caused by the high steam/brine velocity through the gap between the top of the baffle plate and the splash plate.

To prevent this throttling effect and allow a greater range of conditions to be tested, the splash plate height was increased by 10" to 32" above the floor of the chamber. It was found that in addition to enabling the greater circulations to be achieved (Series 4) a reduction in the flash chamber length for complete flash-off was also obtained.

To investigate this effect further, a similar test with a splash plate 27" above the floor of the chamber was completed (Series 11). The results from these three tests are plotted on Fig. 17. It can be seen that although the curves for the 32" and 27" positions are similar, the curve for the 22" position differs slightly - the slope being less steep and the scatter of the experimental points greater. This is due to the curve being from early data, after/

after which, further refinements to the equipment and technique were made. However, it was considered that these results were sufficiently accurate for inclusion in this report.

(b) Splash Plate Length

Early examination of the results indicated that the length of the splash plate had an important bearing on the effective flash chamber length. In addition to the 10" long plate used for most of the work, plates 5" and 15" long were also fitted and tested and compared with similar tests with the 10" plate. Fig. 18 shows the results of these tests.

As could be expected, the splash plate length must be considered when estimating the chamber length.

7. RESULTS

Experimental data is presented in tabular and graphical form. Detailed results are shown in a series of tables (Appendix 2) from which curves of stage efficiency against chamber length are drawn for several parameters (e.g. brine circulation, vapour temperature and chamber temperature drop). In addition, constant efficiency curves are presented for the 99% efficiency range to indicate change in chamber length with variation in each of the parameters mentioned above.

In order to assist interpretation of the curves, it is worth noting that the efficiency data can be studied under two headings: 1) the effect of fluid and thermodynamic properties on chamber length, and 2) the effects of internal chamber geometry on chamber length.

Before examining the data in detail, certain points of experimental procedure should be noted. In general, when fluid properties were being examined, baffle and splash plate dimensions were maintained constant (brine transfer duct constant) except where extreme conditions were under test. In these latter cases, information obtained from tests examining the effect of variation in baffle - splash plate dimensions were used to correlate the extreme data with standard conditions.

8. DISCUSSION OF RESULTS

8.1 Chamber Geometry & Fluid Flow Properties

The principal findings of this investigation are presented in the accompanying curves (Figs. 6 to 18 inclusive). As indicated in the previous section, the experimental work was tackled under two broad headings. The effect on chamber length of:

1) thermodynamic and fluid flow properties

and

2) internal chamber geometry.

8.2 Flash Chamber Efficiency

Before discussing these effects in detail, it is appropriate to examine the concept of chamber efficiency and its efficacy in establishing the optimum chamber length for a given set of conditions.

The chamber efficiency η_s was defined as

$$\eta_s = \frac{D_A}{D_A + D_B}$$

Where D_A and D_B were the quantities of distillate produced respectively in sections A and B of the test chamber. It can be seen from the efficiency - stage length curves (Figs. 6 to 18) that the fall in efficiency for a small change in chamber length is substantial. Now, the main resistances in the vapour flow path from brine surface to condensing tube surfaces are:

1) the/

1) the resistance to vapour release from the brine by the foam

2) the orifice effect between the splash plate tip and the chamber wall (variable). (Fig. 4).

3) the entrainment separator

and 4) the tube bundle with its attendant physical and diffusion resistances.

Of these four factors, the orifice effect (2) is the principal variable for a fixed set of conditions, since the effect of foam height is reasonably constant.

Considering this effect, it is evident that the pressure difference across the splash plate tip is proportional to the square of the vapour velocity in the plane of the splash plate. Hence, a small change in vapour velocity will mean a substantial change in pressure drop. As the droplet separation and condensing system did not vary and the cooling water system for the test chamber was a constant heat sink for fixed conditions, an increase in pressure drop across the splash plate would lead to an increase in pressure on the brine below the splash plate. This effect was evident in superheat of the brine of which vapour release in section B of the test chamber was a measure. Hence, this square law effect could give a rapid fall in chamber efficiency with movement of the adjustable chamber wall, after the point of initial deviation from the 100% efficiency condition.

Owing to the difficulty in fixing the point at which a given efficiency curve/

curve started to fall from the 100% line, it was decided to use the 99% point as the maximum efficiency value which could be determined with reasonable accuracy. Throughout this work, the chamber length at the 99% efficiency point has been utilised as the criterion for optimum chamber length.

8.3 Flow of the Two Phase Mixture

It is convenient at this point to examine the flow of the liquor and two phase mixture in the flash chamber. Visual observation and photographic records (Appendix 4) indicated that the brine entering the test chamber did not commence vapourising until some distance after the entry orifice (Fig. A4. 1); thereafter, vapourisation was progressive. It was established at an early stage that the time required for the two phase mixture to reach equilibrium in the flash chamber was the fundamental parameter in estimating chamber length. However, previous theoretical and experimental work by others, (1), (2) and (3) etc., did not hold out much hope of predicting this time theoretically for a fluid of variable density flowing in a variable cross section duct at sub-atmospheric pressures. Also, the problem of establishing the point at which vapourisation commenced was difficult, because (a) the position of the "flash line" fluctuated due to liquor turbulence in the brine transfer duct, and (b) the turbidity of the liquor which prevented observation of the position of the flash line in the centre of the duct. Nevertheless, it was possible to observe changes in the general position of this "flash line" for different conditions and hence predict the qualitative effect on chamber length. As a consequence

of/

of these difficulties, an empirical approach was adopted and the effect of variations in certain fluid properties and chamber dimensions on equilibration time and hence chamber length were studied.

8.4 Brine Circulation (Figs. 6 and 7)

From Fig. 7, it was observed that chamber length was directly proportional to brine circulation for the standard conditions (150°F, 3°F per stage). Over the range of flows tested, there was no pronounced evidence of a non-linear characteristic in the rate at which the chamber length increased with increasing circulation. The curves appeared to indicate that initial vapourisation and rate of vapourisation were reasonably constant, and the time required for equilibration was mainly dependent on circulation. The scatter of points obtained for the 350,000 lbs/hr.ft. curve (Fig. 6) can be attributed to the fact that they were taken over several test runs. Exact repetition of test results was difficult as the degree of accuracy in plant control required to repeat a given test was exceptional, (e.g. 1 mm error in reading on differential manometer between parts A and B of the test chamber could introduce an error of 1% in stage efficiency).

8.5 Interstage Temperature Difference (Figs. 8 and 9)

It was a particular plant characteristic that variation of temperature difference between an existing and some chosen value was generally more difficult to control than corresponding fluid flow or temperature level change.

Hence, /

Hence, the use of non-integral values (e.g. 1.8; 3.3; 5.7°F). However, it was still possible to observe a distinct trend (Fig. 9) which appeared consistent, in that increasing temperature difference led to increasing chamber length, although the change in chamber length with variation in temperature difference was not constant and decreased with increasing temperature difference.

As stated earlier (Section 8.3), the parameter controlling chamber length was the time required for the two phase mixture to reach equilibrium. The implication of the temperature difference test series was that this time was not constant relative to temperature difference. However, with one exception, experimental evidence to support this claim could only be inferred from the data (Fig. 9). The exception was the variation in "flash line" position with temperature difference. These data (Fig. 9), indicated an increase in the length of two phase mixture flow path within the baffle system with increasing temperature difference, thus tending to reduce the distance required for equilibration in the flash chamber.

A study of equilibration time (4) under static conditions, indicated that the change in vapourisation rate with time followed a law with an exponential decay form. Application of this to evaporator flow conditions was difficult but indications were that rate of vapourisation would increase with increasing temperature difference.

The combined effect of variations in "flash line" position and vapourisation rate could explain the form of the temperature difference - chamber/

chamber length curve (Fig. 9).

8.6 Temperature Level (Figs. 10-13)

Examination of the temperature - chamber length curve (Fig. 11) indicated that the controlling factor was the variation in vapour specific volume with temperature.

To explain this assertion, it was again necessary to consider the two phase mixture residence time. The mixture mass flow rate was essentially constant during these tests, hence the mixture velocity and residence time were functions of the mixture specific volume, which was in turn controlled by the vapour specific volume. Hence, the temperature dependence of the vapour specific volume indicated that the mixture residence time and flash chamber length were inversely proportional to the temperature.

It was noted that the full effect of the change in vapour specific volume with temperature, between 200°F and 100°F would not be reflected fully in the chamber length - temperature curve as the liquor volume was at all times a significant portion of the mixture volume.

8.7 Low Temperature Tests

As indicated in section 6.6., difficulties were encountered when trying to run tests at standard conditions (Section 6.1) but at temperatures near 100°F. The low temperature tests which were done showed a much more gradual drop in stage efficiency as the chamber length was reduced past/

past the critical point. An important aspect of these tests was the temperature-pressure relationship at low temperatures, where the pressure drop for a given temperature difference became small in comparison with the ratio at the standard test temperature of 150°F. Thus, the pressure potential to promote flashing was small and a greater residence time was required to allow the transfer of heat from the baffle formations and to overcome the resistances due to the head of foam and brine.

By employing the information obtained in test series 4, 7, 8 and 11, corrections were made to the two curves at a circulation of 250,000 lbs/hr. ft. to give an equivalent 99% point at the standard conditions of 300,000 lbs/hr. ft. at 105 and 100°F. These points were plotted on Fig. 11, and although the cumulative error (test plus correction error) may be greater than that for the normal tests where the information is obtained directly, the indications were that the rate of change of chamber length increased further with decrease in temperature below 120°F.

8.8 Brine Level (Figs. 15 and 16)

The final parameter studied dealing with the flow of the brine or its properties was the brine level. It has been established, in commercial practice, that fluctuations in brine level could cause disturbances detrimental to evaporator performance, so that a measure of the effect on chamber efficiency of fluctuations was required.

In/

In this series of tests, the relationship between brine level and transfer duct dimensions was critical. Reference to Fig. 16 will show that levels above, but close to the baffle height, had only a small influence on chamber length, whereas levels approaching the splash plate height had a significant effect on chamber length. This effect could be attributed to the restriction of the two phase mixture flow at a critical point, where the specific volume of the mixture was approaching the maximum before vapour release. In other words, the mixture flow was no longer controlled solely by the baffle-splash plate system but by the brine level and splash plate. The consequent increase in mixture velocity and reduction in residence time led to longer chamber lengths with increasing brine level.

There was also a further, less critical, effect that was the movement of the "flash line". It was observed that increasing brine level caused this line to move up the baffle duct, thus reducing the equilibration distance and time with a resulting increase in stage length. The combination of these two effects was adjudged the cause of the non-linear characteristic obtained.

8.9 Interstage Brine Transfer Arrangements (Fig. 14)

For most of the test work, the standard baffle arrangement (Section 6.1) was used. However, variations in baffle dimensions were necessary for the range of stage temperatures normally used in evaporator design where the baffle plate is closest to the plane of the first orifice for high temperatures, and/

and further away for the lower temperatures.

The results (Fig. 14) indicated that the baffle distance from the first orifice was not an important factor in the estimation of chamber length. There was an indication that the slope of the curve for inefficient chamber lengths varied with the baffle dimension, but this was not considered of importance as all flash chambers should be designed for 100% efficiency.

There was, however, a significant increase in chamber length with decreasing baffle height. It was established that a rise in brine level above the baffle led to an increase in chamber length. This could be attributed to movement of the "flash line" into the chamber as the level rose, thus reducing the mixture residence time in the flash chamber. Also, reduction in baffle height decreased the mean path of the brine and two phase mixture across the chamber, necessitating a larger chamber.

From the above, it can be concluded that for similar running conditions, the baffle distance from the first orifice has little effect on the effective chamber length required for complete flash-off, but if the height of the baffle is reduced, then the effective length for complete flash-off will require to be increased.

8.10 Splash Plate Arrangements (Figs. 17 and 18)

During the test work, it was found that the height and length of the splash plate fitted above the baffle plate was an important parameter.

1) Splash Plate Height - The results (Appendix 2) show that the higher the splash plate above the top of the baffle plate, the shorter the chamber need be to ensure complete flash-off. As in the previous section on baffle height, the length of the mean path of the brine is increased with the higher splash plates allowing the brine to have greater residence time in the chamber. Reducing the plate height also increases the pressure drop through the orifice between the top of the baffle plate and the splash plate, and the resulting higher upstream pressure tends to suppress flashing within the duct. Thus, a greater percentage of the flash-off takes place after the baffle and necessitates a longer chamber for equilibration.

2) Splash Plate Length - The results obtained for three different splash plate lengths are shown in Fig. 18. The results indicate that the orifice between the tip of the splash plate and the downstream wall controls the rate of flash-off in the chamber. Obviously, if the distance between the tip of the plate and the wall was reduced to zero, the flash-off would be completely suppressed.

An increase in splash plate length does not increase the required chamber length by the same amount. Thus, some flashing must take place under the splash plate irrespective of the splash plate length. This would indicate that with very long plates, a proportion of the flash-off would occur under the plate and be completed in the gap between the plate and the wall, and this latter distance would be a minimum for very long plates.

NOTES ON RUNNING CONDITIONS FOR FIGURES 6 - 18

Figure 6 - Chamber lengths for a range of brine circulations - Series 4.

Range of brine circulations - 200,000 - 500,000 lbs/hr.ft. in steps of 50,000 lbs/hr.ft.

Interstage temperature drop - 3°F per stage.

Brine temperature - 150°F (see note)

Interstage Brine Transfer Arrangement

Baffle plate 12" high, 6" from the plane of the vertical 1st orifice (see note).

Splash Plate Arrangement

Splash plate 10" long, 32" above the floor of the chamber.

Symbol System for Experimental Points

• - 500,000 lbs/hr.ft.
⊙ - 450,000 "
◇ - 400,000 "
× - 350,000 "
⊗ - 300,000 "
⊠ - 250,000 "
◈ - 200,000 "

Note: The available interstage pressure drop at 150°F was not sufficient to allow the brine circulations of 450,000 and 500,000 lbs/hr.ft. to flow into the chamber without a very high brine level in the upstream stage. To overcome this problem, the baffle plate distance was moved to 9" from the 1st orifice, and the brine temperature increased to 175 - 180°F. The results were later corrected by using information developed from Series 6, to give equivalent chamber lengths at 150°F. No correction was required for the different baffle spacing (Series 7).

Figure 7 - 99% Curve

The points where the curves in Fig. 6 pass through the 99% efficiency points are plotted on this figure for each brine circulation. The curve is extrapolated at low brine circulations. If the circulation is reduced to zero, the splash plate will limit the minimum chamber which can be obtained.

EFFECT OF VARYING BRINE CIRCULATION RATE.

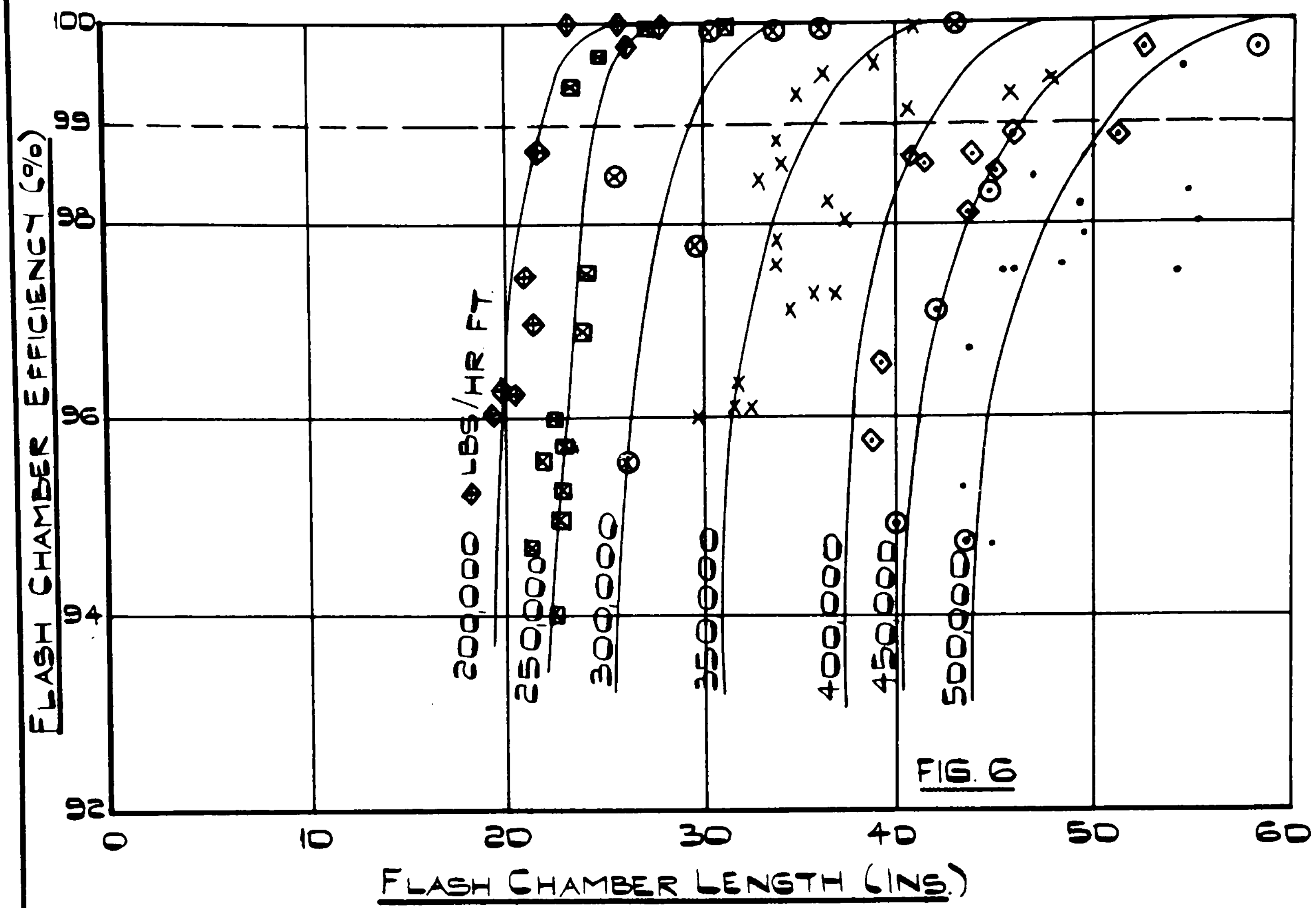


FIG. 6

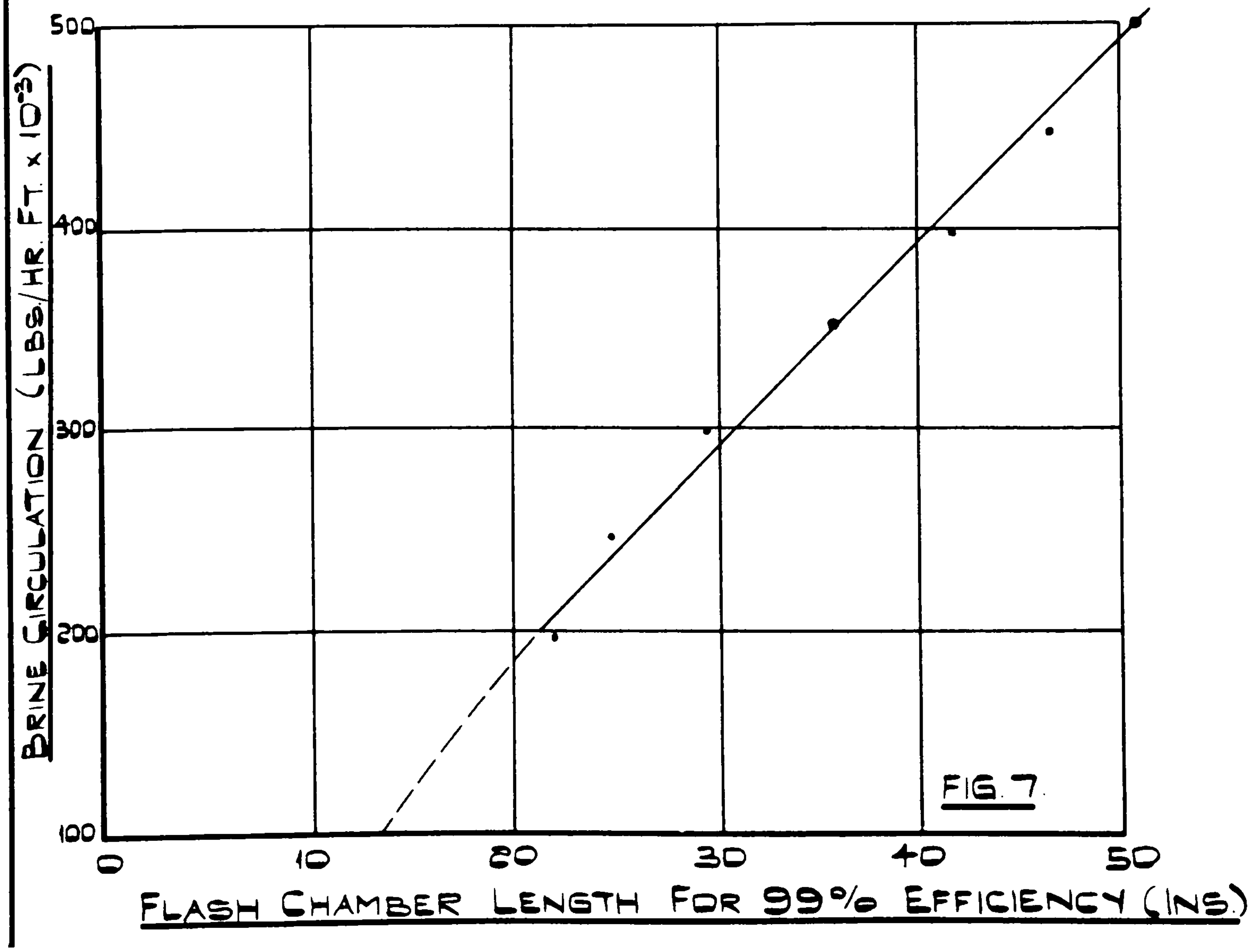


FIG. 7

Figure 8 - Chamber lengths for a range of interstage temperature differences - Series 5.

Range of temperature differences - 1.8°F to 8°F per stage.

Brine circulation - 250,000 lbs/hr.ft.

Brine temperature - 150°F.

Standard brine transfer and splash plate arrangement (Section 4.)

Symbol System for Experimental Points

• - ΔT = 1.8°F
⊙ - ΔT = 3.3°F
× - ΔT = 5.7°F
⊗ - ΔT = 8.0°F

The curve at 3°F is drawn from information obtained from Series 4.

Note: The high flash-off for the test at 5.7°F and stage lengths of 27 & 29" caused carry-over and an accurate reading of distillate production could not be obtained while the test was in progress. It was later discovered for these two tests that the actual flash-off was less than 5.7°F. For the test at 8°F per stage, the separator area was increased and the distillate purity was improved.

Figure 9 - 99% Curve

If no flash-off takes place in the chamber, the gap between the tip of the splash plate and the moveable wall can be reduced to zero - i.e. the effective chamber length becomes 10".

EFFECT OF VARYING TEMPERATURE DROP (ΔT) PER STAGE

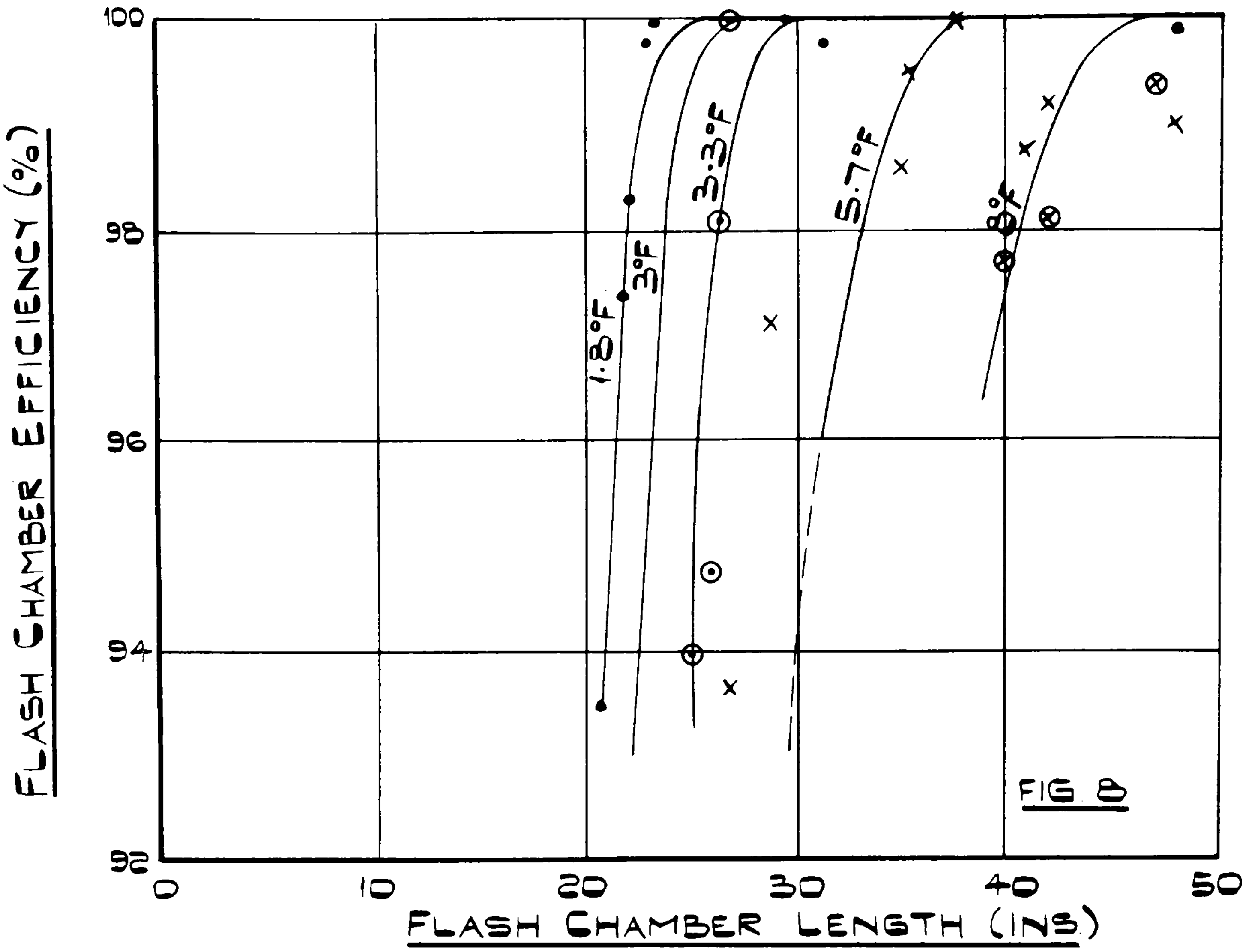


FIG 8

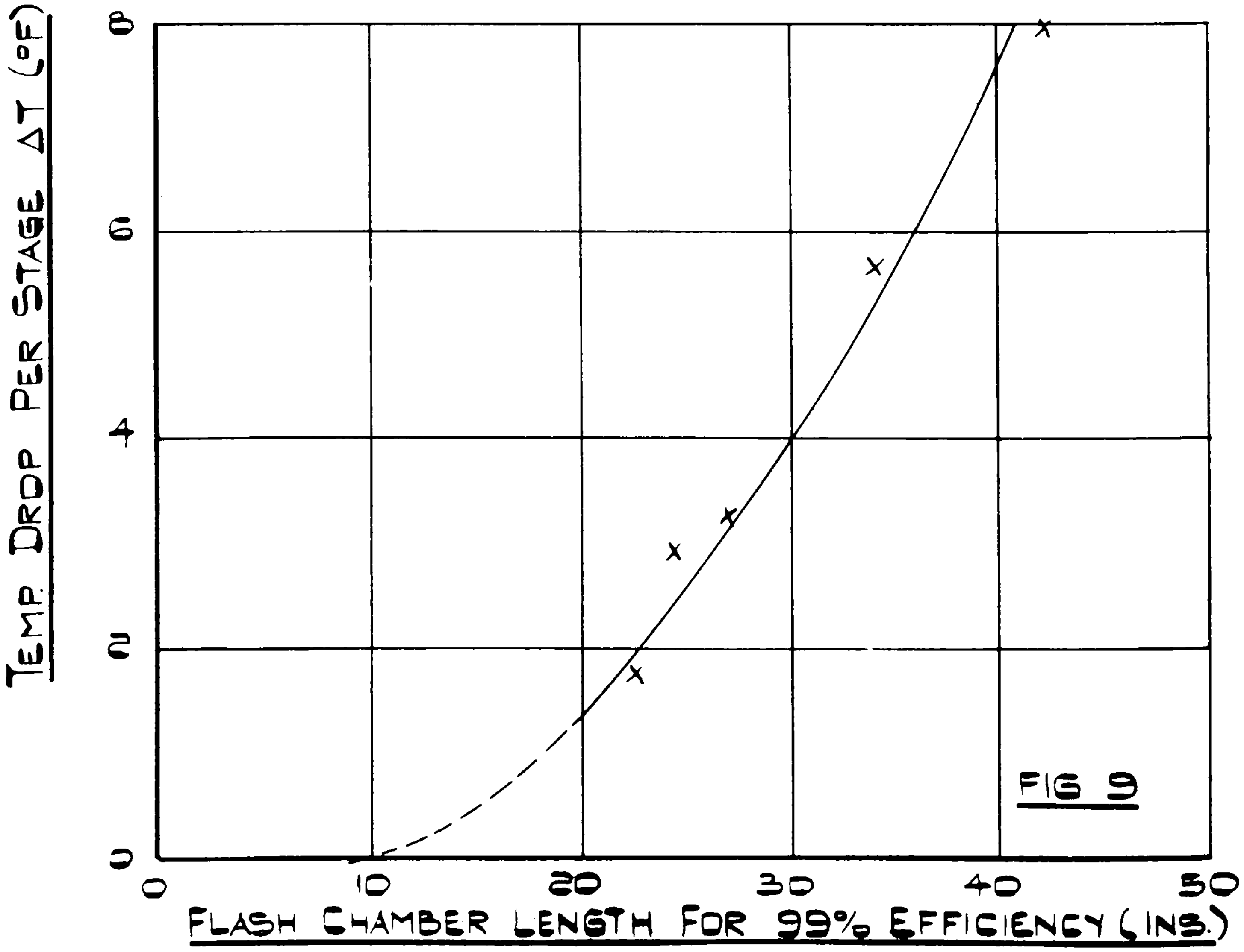


FIG 9

Figure 10 - Chamber lengths for a range of brine temperatures - Series 6.

Range of brine temperatures - 125° - 200°F.

Brine circulation - 300, 000 lbs/hr. ft.

All other conditions standard as in Section 4.

Symbol System for Experimental Results

• - 200°F.
⊙ - 175°F.
× - 125°F.

The curve at 150°F is drawn from information obtained in Series 4.

Figure 11 - 99% Curve

The 99% points are taken from the curves on Figs. 10, 12 and 13. The points from Figs. 12 and 13 have been corrected to adjust them to the standard baffle and splash plate arrangement and a brine circulation of 300, 000 lbs/hr. ft. The correction is approximate only.

EFFECT OF BRINE TEMPERATURE ON CHAMBER LENGTH.

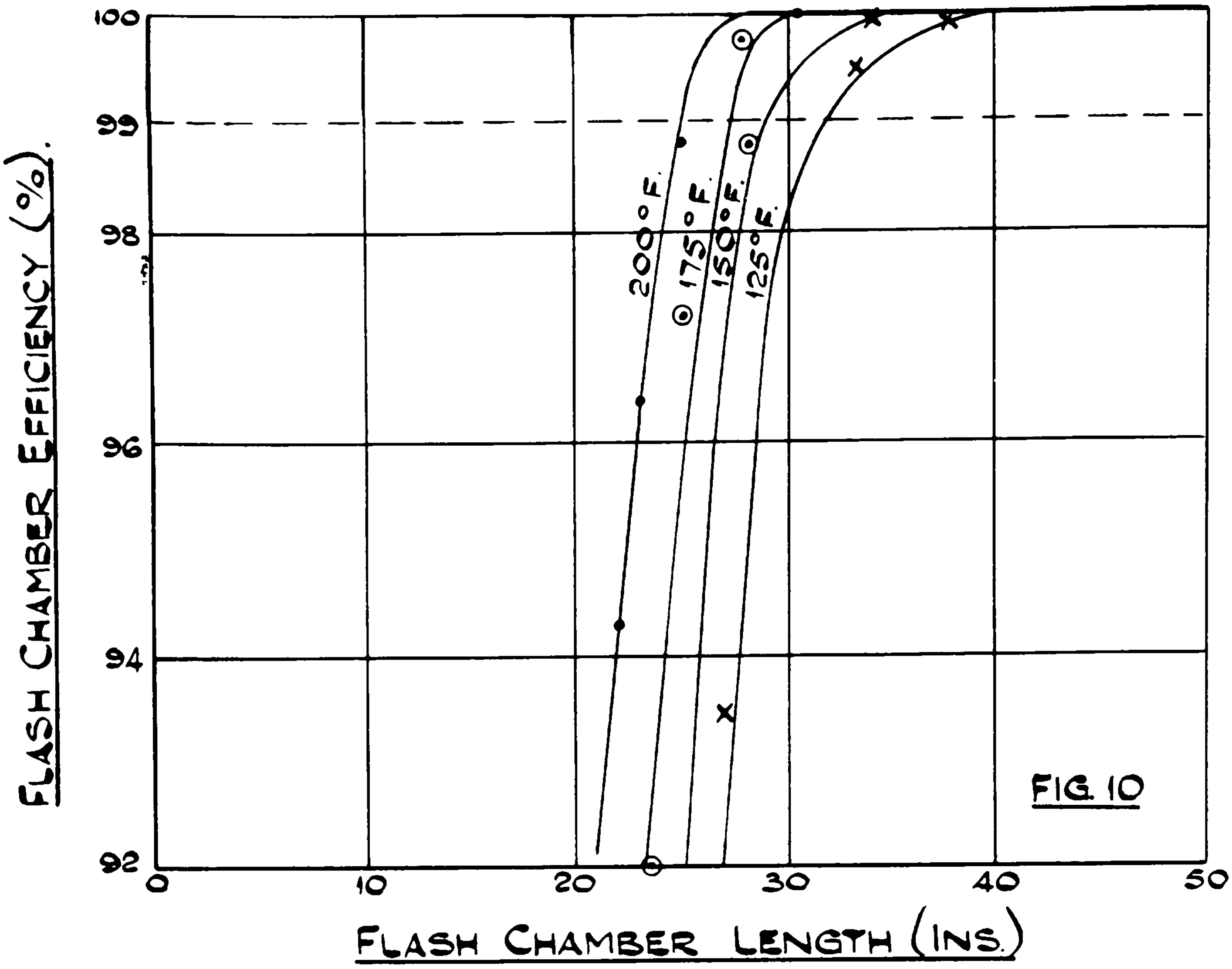


FIG. 10

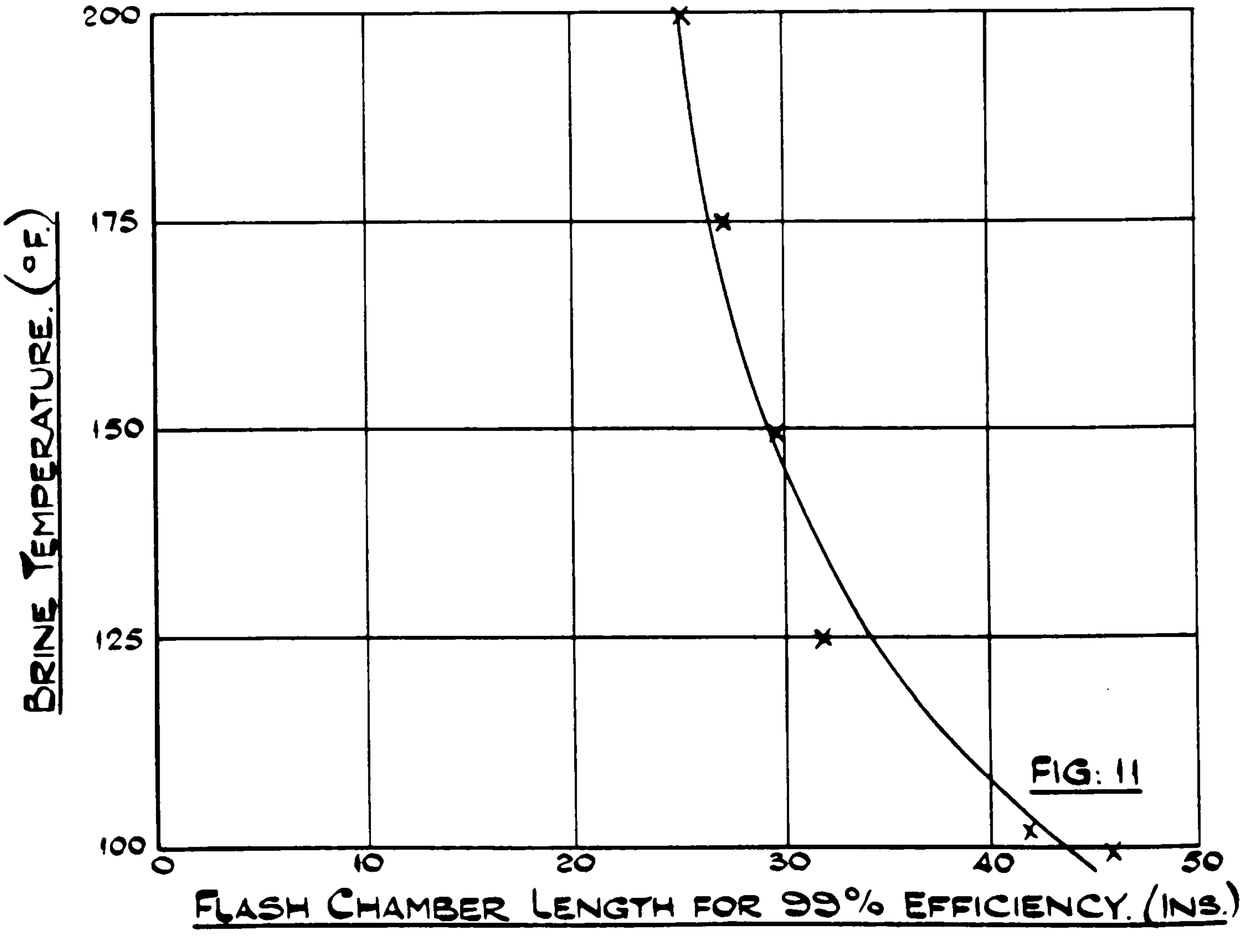


FIG: 11

Figure 12 - Chamber lengths at low temperatures - Series 6.

The curve at 105°F is drawn for the following experimental conditions:-

Brine circulation - 250,000 lbs/hr.ft.

Brine temperature - 105°F.

Interstage temp. drop - 3°F.

Splash Plate Arrangement

5" long plate, 32" above the floor of the chamber.

Interstage Brine Transfer Arrangement

Baffle plate 12" high, 6" from the first orifice.

Also plotted on Fig. 12 is the corresponding curve for similar conditions, but at 150°F, and the 99% efficiency point for the 105°F condition if the equation given in Section 9 held below 125°F.

Figure 13 - Two further tests at 100°F are shown.

1) Brine circulation = 250,000 lbs/hr.ft.

2) Brine circulation = 200,000 lbs/hr.ft.

Both tests were conducted at 3°F temperature drop per stage. The standard splash plate of 10" long, 32" high was used with a baffle of height 6", 12" from the 1st orifice.

Again the 99% efficiency point is calculated for Test (1).

LOW TEMPERATURE TESTS.

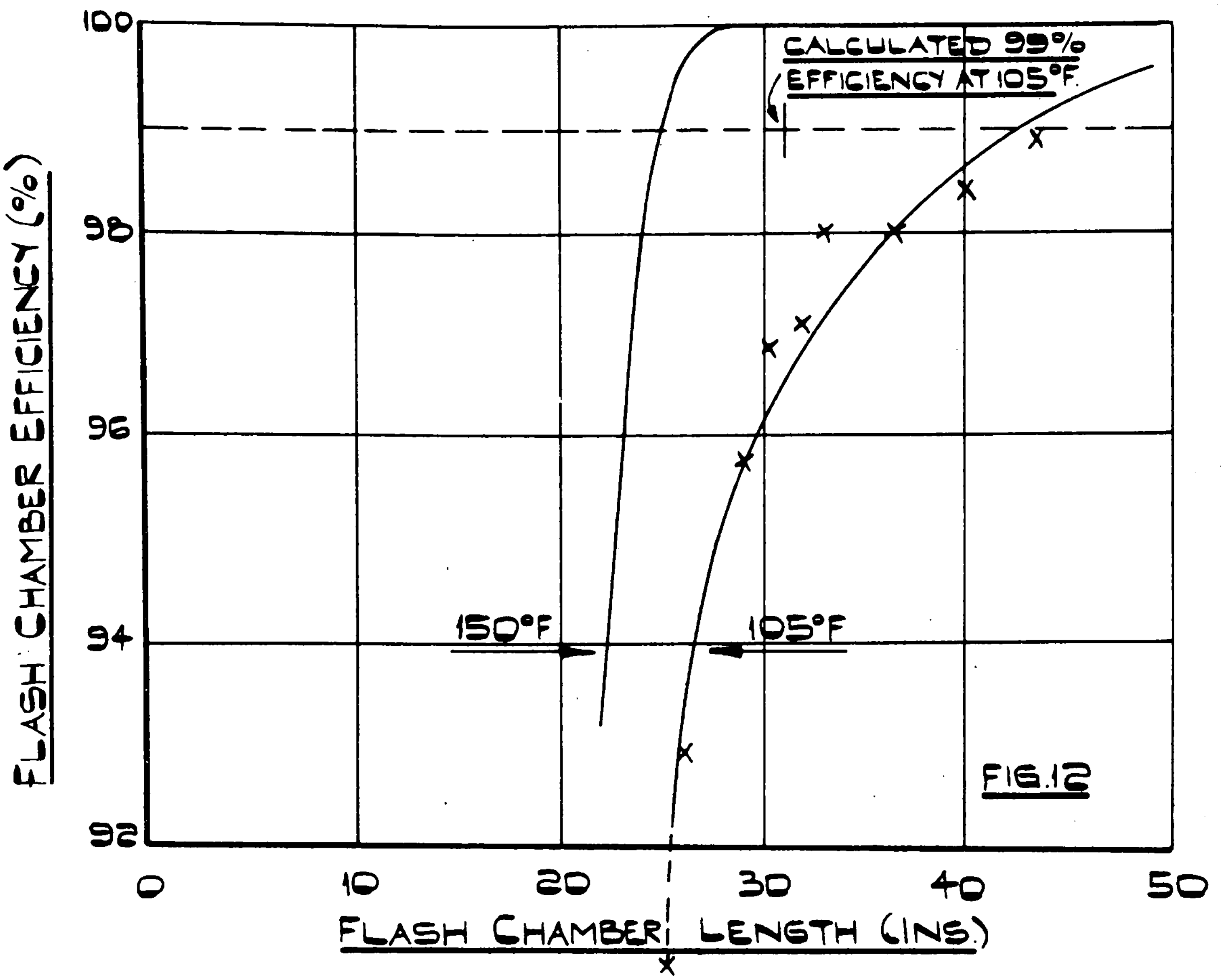


FIG. 12

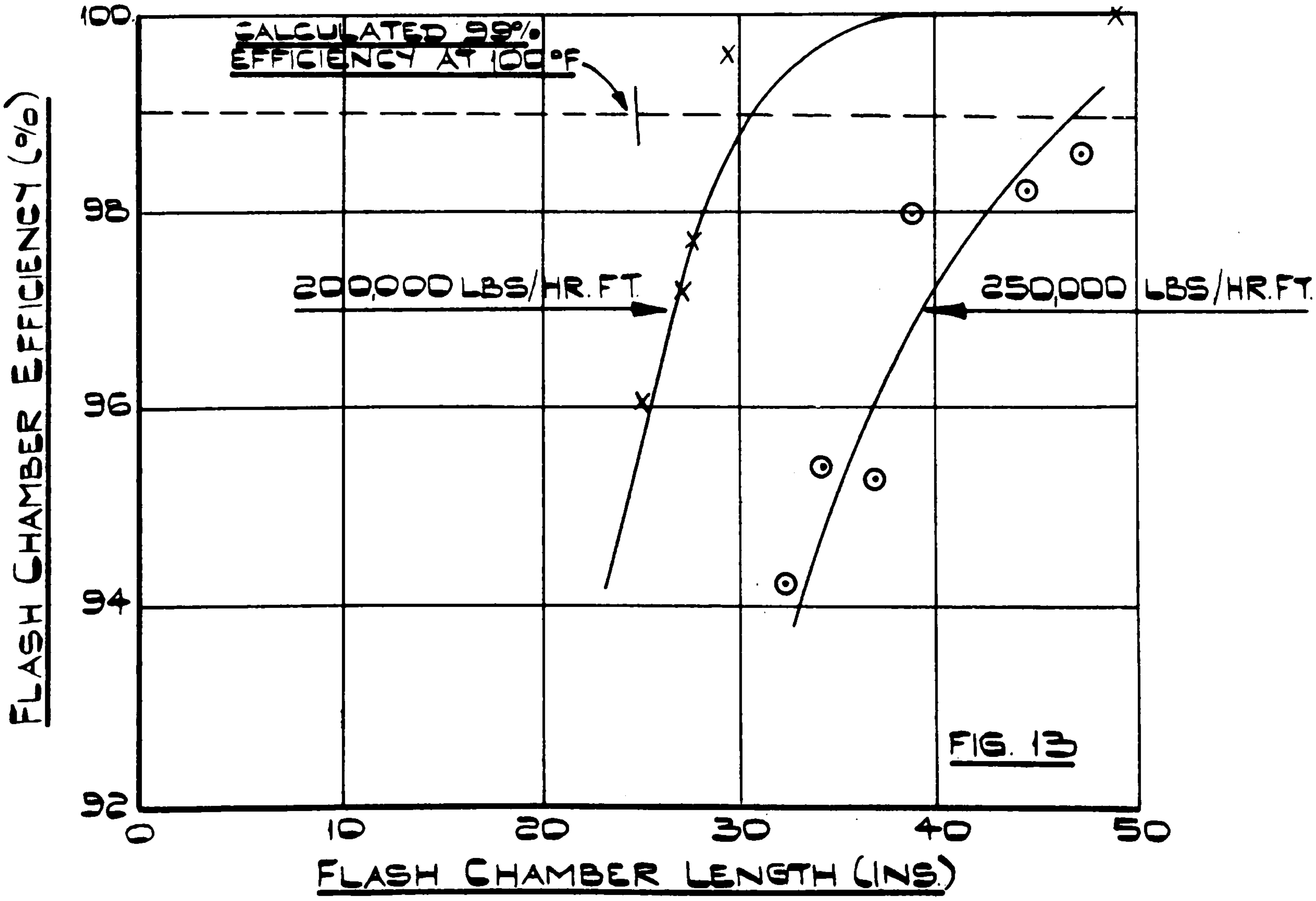


FIG. 13

Figure 14 - Effect of different interstage brine transfer arrangements - Series 7.

Running conditions

Brine circulation - 300,000 lbs/hr. ft.
Brine temperature - 150°F.
Interstage temp. drop - 3°F.

Splash Plate Arrangement

Standard dimensions of 10" long, 32" high.

Interstage Brine Transfer Arrangement

× - 6" high baffle plate, 12" from 1st orifice.
⊙ - 12" " " " 3" " " "
• - 12" " " " 9" " " "

The curve for a 12" high baffle plate 6" from the 1st orifice (from Series 4) is shown as a dotted curve.

EFFECT OF VARYING BRINE BAFFLE DIMENSIONS – FIG. 14

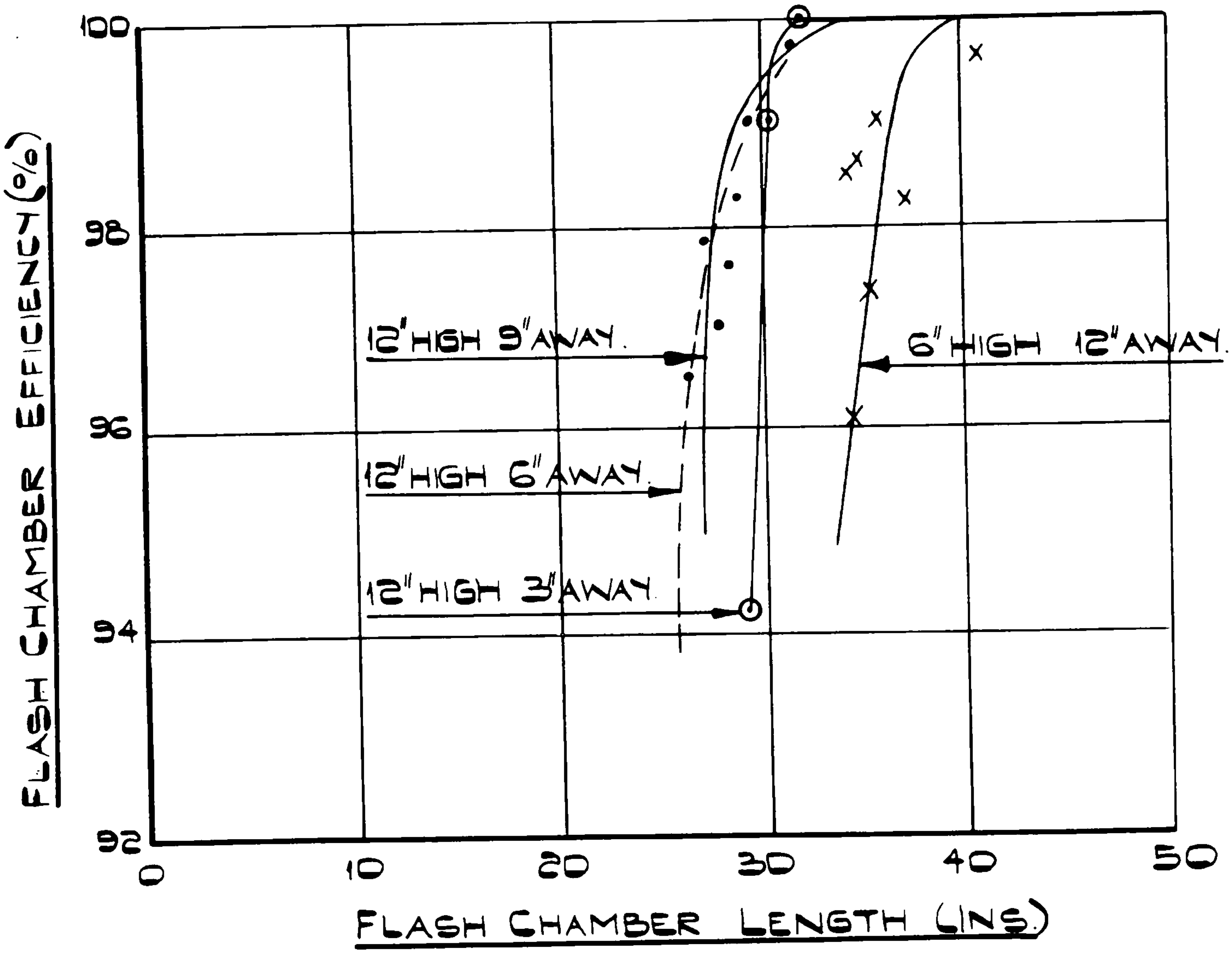


Figure 15 - Chamber length at different brine levels - Series 8.

Running Conditions

Brine circulation - 300,000 lbs/hr. ft.
Brine temperature - 150°F.
Interstage temp. drop - 3°F.

Splash Plate Arrangement

Standard conditions of 10" long and 32" high.

Interstage Brine Transfer Arrangement

12" high baffle plate, 9" from the 1st orifice.

Brine Levels - Symbol System

⊗ - 12" high - from Series 7.
• - 15" "
⊙ - 18" "
× - 22.5" "

Figure 16 - 99% Curve

The 99% points are taken from Figure 15.

EFFECT OF VARYING BRINE LEVEL.

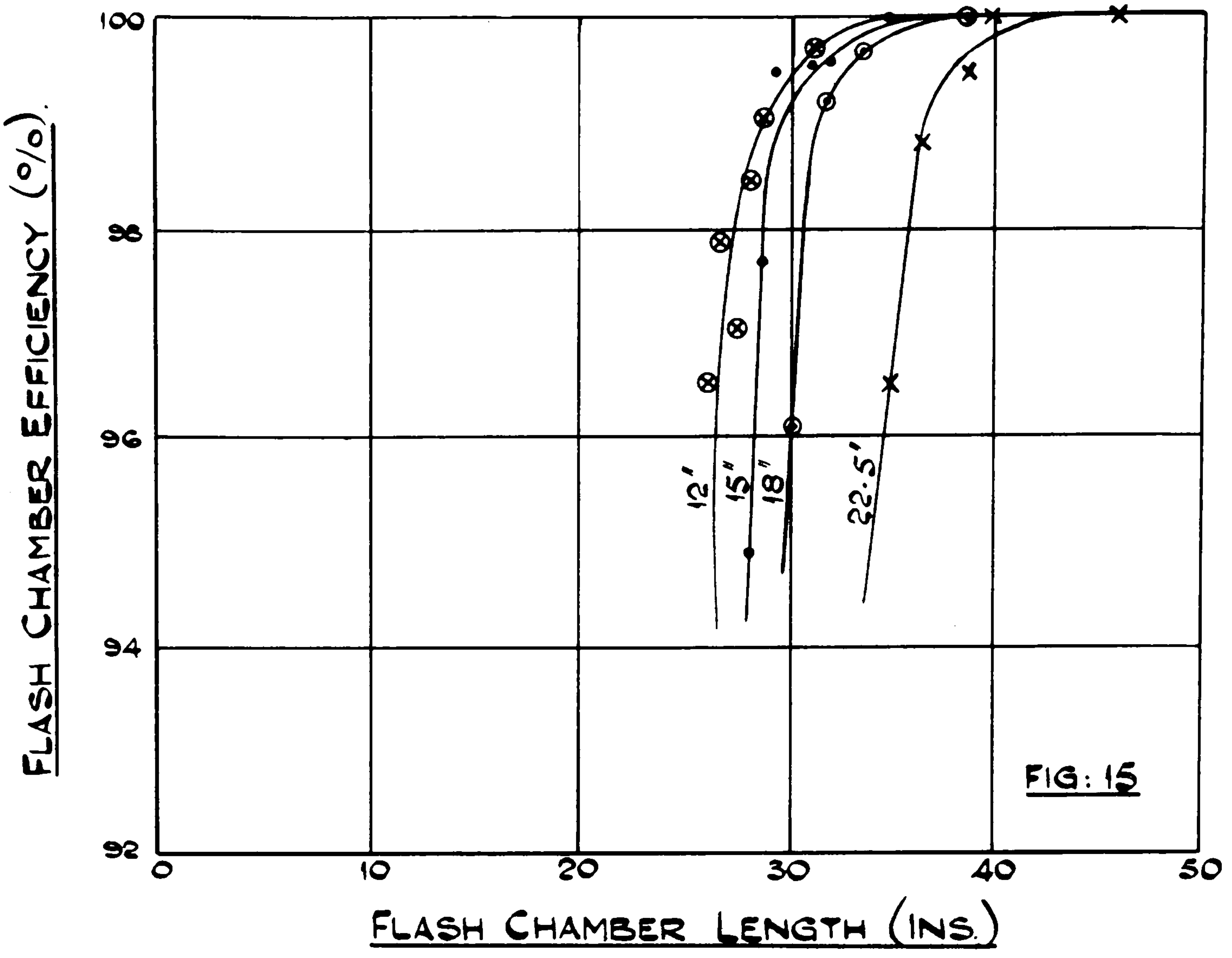


FIG: 15

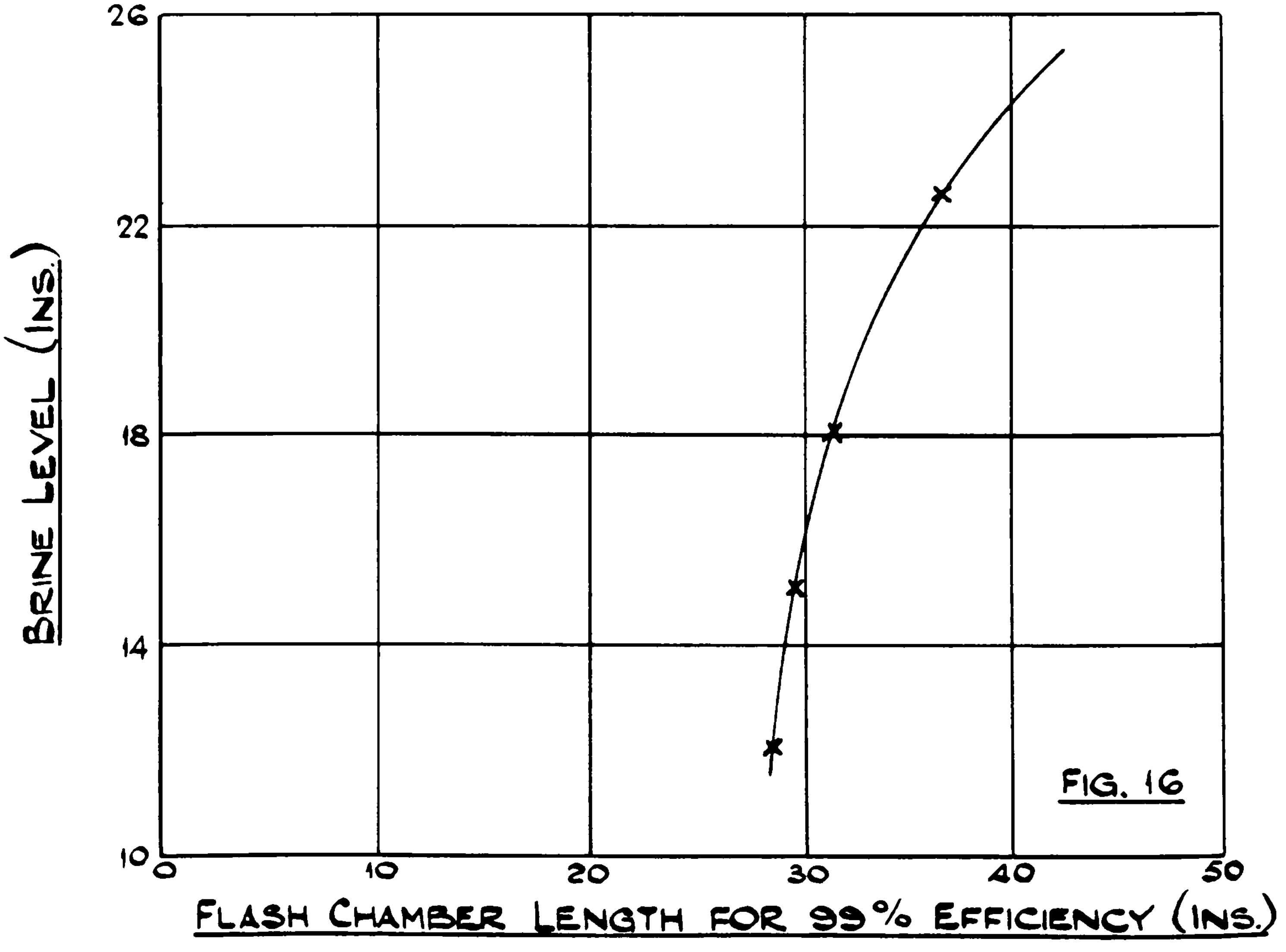


FIG. 16

Figure 17 - Chamber length at different splash plate height - Series 11.

Standard running conditions of 250,000 lbs/hr.ft. at 150°F and 3°F temp. drop per stage. Standard baffle - 12" high, 6" from the 1st orifice.

Splash Plate Dimensions - Symbol System

• - 10" long splash plate 32" high.
× - 10" " " " 27" "
⊙ - 10" " " " 22" "

Figure 18 - Chamber length at different splash plate lengths - Series 11.

Conditions as in Fig. 17, but splash plate height fixed at 32".

Splash Plate Length - Symbol System

• - 5" long splash plate
× - 15" " " "

The curve for a 10" long plate is drawn from information obtained in Series 4.

EFFECT OF VARYING SPLASH PLATE LENGTH & HEIGHT.

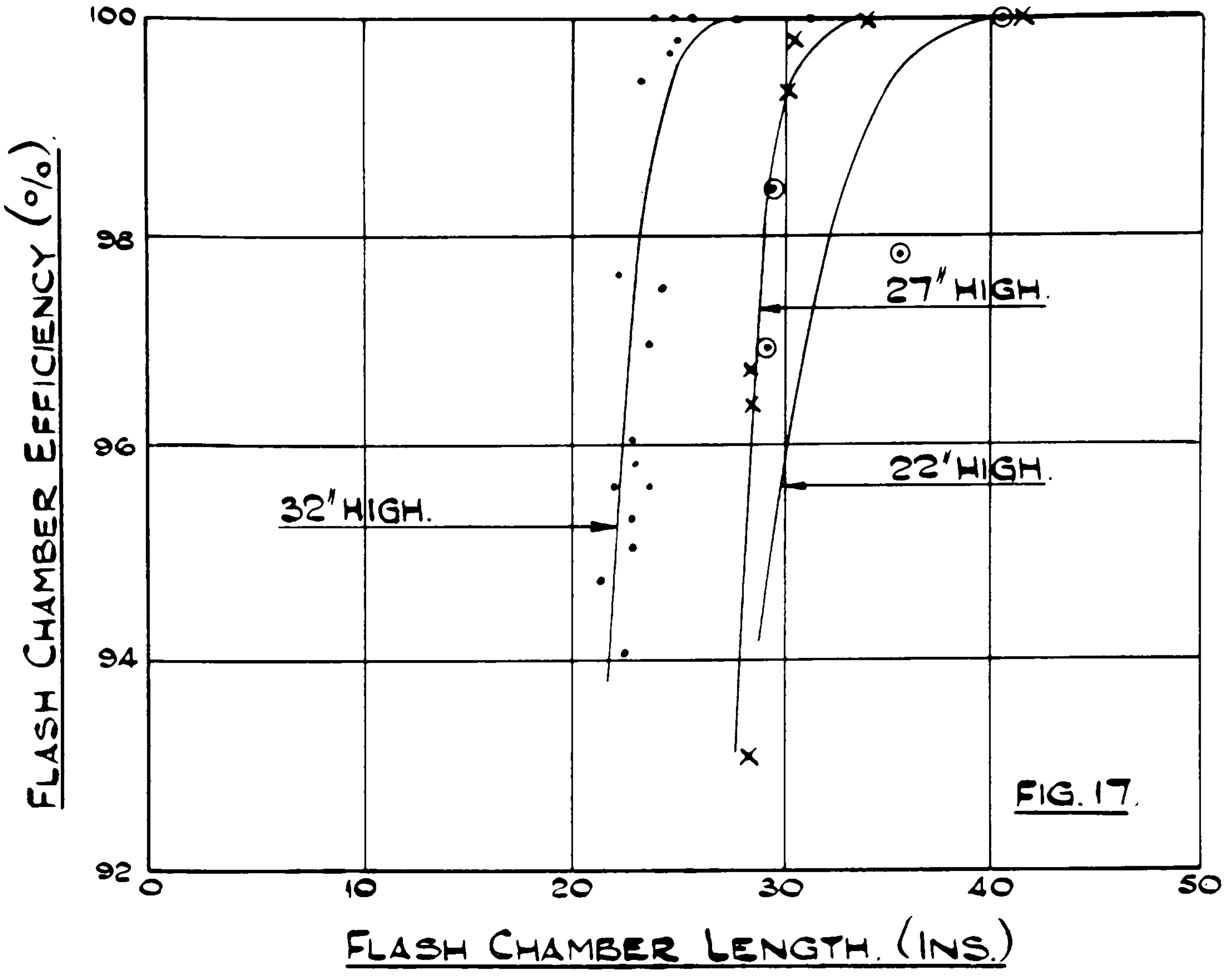


FIG. 17.

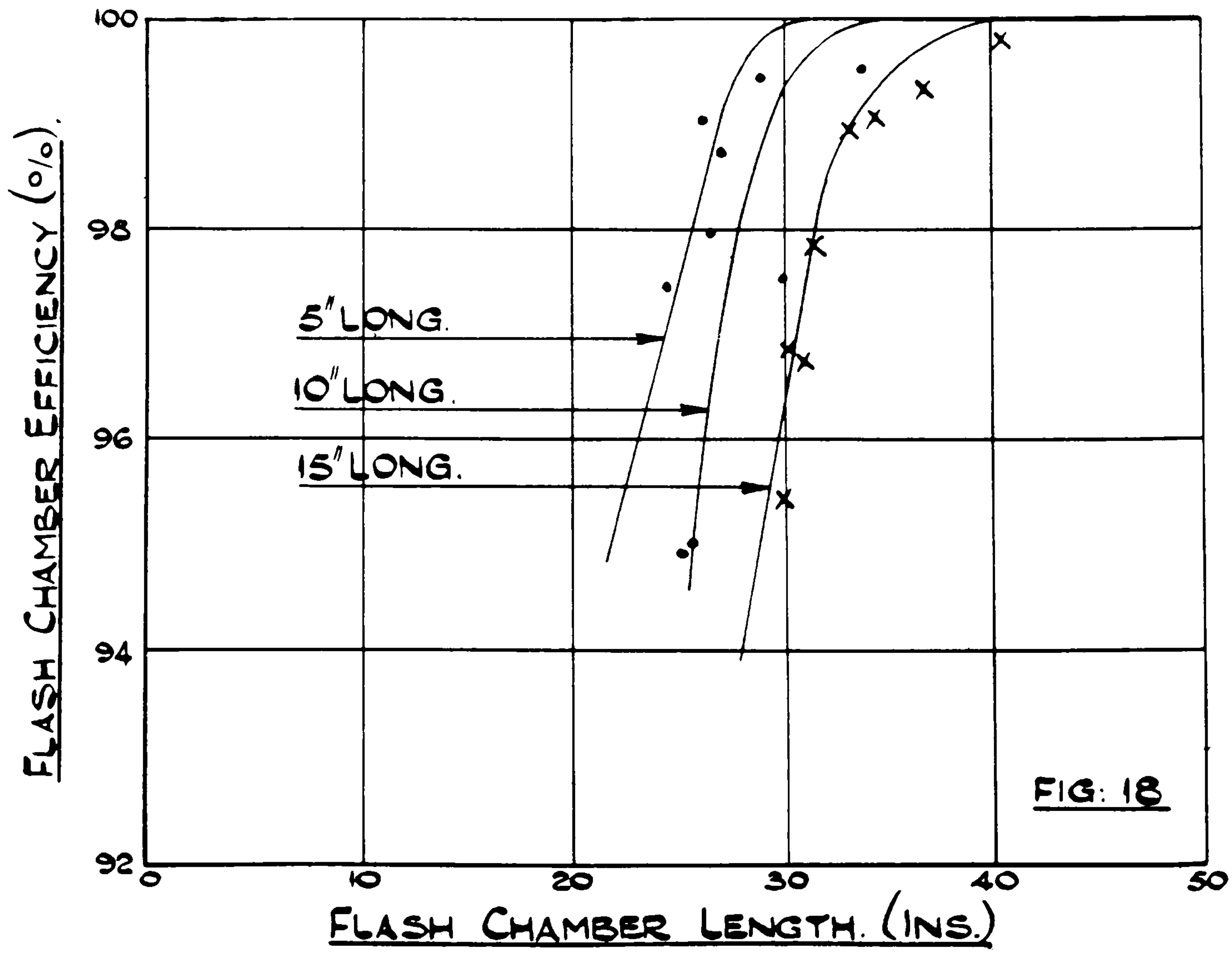


FIG: 18

9. APPLICATION TO THE DESIGN OF FLASH CHAMBERS

An empirical method for the estimation of flash chamber lengths for different running conditions is given below. The method consists of finding the chamber length required for 99% efficiency for any circulation within the range specified and modifying the length for different temperature drops, temperature and splash plate conditions.

Figs. (6 - 18) have been examined to determine an empirical equation which would enable the minimum chamber length to be calculated for any condition covered by the experimental data.

The basic chamber dimension is the distance between the splash plate tip and the opposite chamber wall. The following parameters apply:

$$Q = 10,000\ L^1 + 85,000 \quad (1) \quad (\text{Fig. }7)$$

$$L^1 = \frac{Q - 85,000}{10,000} \quad (2)$$

where Q = Brine flow lb/hr. ft.

L^1 = Length in inches between splash plate tip and wall.

This applies at 150°F and 3°F stage temperature drop. To correct for other conditions:-

$$L = \frac{(Q - 85,000)\ F_1\ F_2}{10,000} + F_3 \text{ ------ } (3)$$

where F_1 F_2 and F_3 are correction factors for stage temperature, temperature difference/

difference and splash plate length respectively.

$$F_1 = \left(\frac{610}{T}\right)^{3.12}$$

$$F_2 = \left(\frac{\Delta T}{3}\right)^{.6}$$

$$F_3 = (3.6 + 0.63\ell)$$

L = Chamber length ins.

ℓ = Splash plate length ins.

ΔT = Stage temperature difference °F.

T = Brine temperature °F abs.

The range of values for which equation (3) can be used are:-

Temperature	-	125°F - 200°F
Temperature drop	-	1.8°F - 8°F
Brine Circulation	-	200,000 - 500,000 lbs/hr per ft. of chamber width.
Brine Level	-	12"
Baffle Plate	-	12" high, 3 - 9" from 1st Orifice
Splash Plate	-	5 - 15" long.
Antifoam dosing	-	1 p.p.m. of feed.
Brine concentration	-	2 : 1

Table 9.1 gives a comparison between experimental results and values of chamber length calculated by equation (3).

TABLE 9.1 Comparison between Experimental Results and Calculated Values for Chamber Lengths at 99% Efficiency

Brine Circ. lbs/hr.ft.	Interstage ΔT °F	Brine Temp. °F	Splash Plate		Baffle Plate		99% Chamber length by Experiment	99% Chamber length by Calculation
			ℓ	H	H	D		
200,000	3.0	150	10"	32"	12"	6"	22.0"	21.4"
200,000	5.0	130	10"	32"	12"	9"	27.0"	27.3"
250,000	1.8	150	10"	32"	12"	6"	23.0"	22.1"
250,000	7.0	150	10"	32"	12"	6"	38.5"	37.4"
254,000	5.8	150	15"	32"	12"	6"	36.5"	38.1"
300,000	3.0	125	10"	32"	12"	6"	32.0"	34.4"
300,000	3.0	190	10"	32"	12"	6"	26.5"	27.6"
333,000	2.3	160	10"	32"	12"	6"	30.0"	33.6"
400,000	3.0	150	10"	32"	12"	6"	41.0"	41.5"
450,000	3.0	175	10"	32"	12"	9"	42.5"	41.9"
500,000	3.0	180	10"	32"	12"	9"	45.0"	45.6"

NOTE The test at a brine circulation of 333,000 lbs/hr.ft. was conducted with brine which had previously been dosed at 5 p.p.m. instead of the usual 1 p.p.m.

APPENDIX 1

DESCRIPTION OF RESEARCH VEHICLE

A1 1 General Description

The research vehicle used in the investigation (Figs. 1 and A1.1) allows the flashing conditions of temperature and flow of any four consecutive stages of a sea water multi-stage flash evaporator to be reproduced. It consists of a separate heat input section, a four stage heat recovery section, and a two stage heat rejection section. The research plant can be run as a complete evaporator except that the small number of stages restricts the overall temperature drop to that of any four stages of a complete commercial unit. A circuit diagram of the plant is shown in Fig. 3 in the main part of the report.

The four flash chambers are each 5'9" long, 1'6" wide and 3'9" high. Provision is made for fitting two vapour/brine separators in the roof of each chamber but normally only one is necessary. The steam passes through the separators and condenses on the heat recovery tubes. The incondensible gases are vented from each stage into the heat rejection section. Distillate is drawn from each stage into measuring cylinders before being mixed and pumped, either to waste or to the factory boiler feed storage tank. The distillate purity from any stage or from the mixture can be recorded on a Crockatt Salinometer and Recorder.

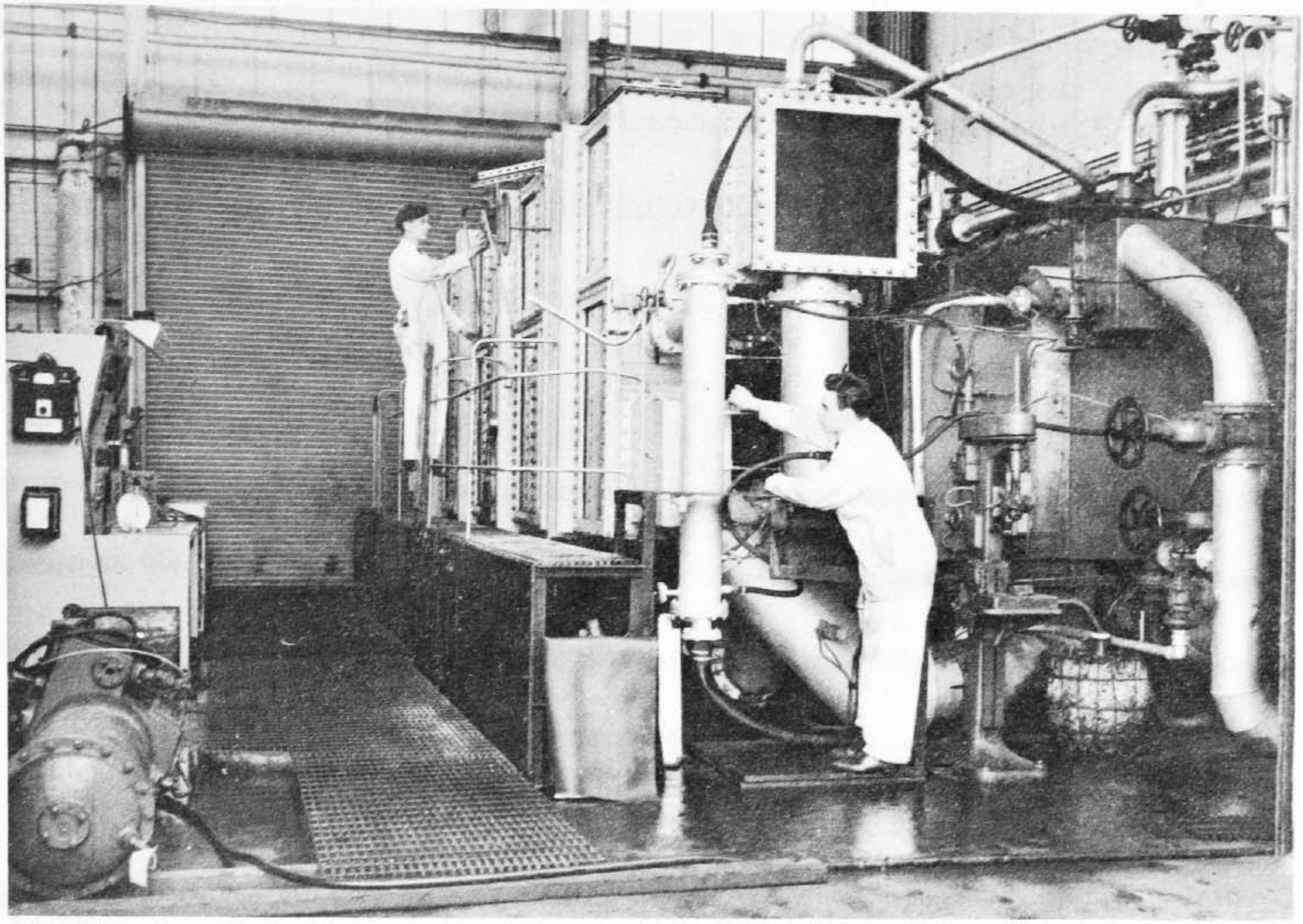


Fig A1.1 End view of the evaporator test rig. The steam flashed off in stage 3B is condensed in the small auxiliary condenser shown attached to the low temperature end of the evaporator. The two stage heat rejection section is on the R.H.S. and the instrument control panel is on the left.

A1.2 Heat Recovery Section

The heat recovery tubes run in a continuous length through the four stages. They are $\frac{3}{4}$" dia. 18 s.w.g. Aluminium Brass tubes, 23'9" long with Rolled Naval Brass tubeplates and interstage support plates. Rubber sealing rings reduce the leakage of steam through the tube clearances in the interstage support plates.

A1.3 Heat Rejection Section

The two stage heat rejection section is not normally used for research purposes and decreases the temperature of the brine before it flows to the main brine circulating pump and the heat recovery section. The vent lines from the heat input section, the preflash chamber and each of the four heat recovery stages, all flow into the second heat rejection stage and finally to a vent condenser where the incondensibles are withdrawn either by a vacuum pump or a two stage steam operated air ejector.

A1.4 Venting

When the test facility was first commissioned, the non-condensible gases were allowed to flow along the heat recovery tubes through the clearances in the interstage support plates down to the fourth stage from where they were vented to the heat rejection section. However, as air leakage into the test evaporator was greater than in a commercial plant (due to the large number of instrument pockets, windows, etc.), this method was found to be

unsatisfactory/

unsatisfactory and the venting was later arranged to come from each stage independently and into the heat rejection section. The tubeplate clearances which had been used as vents were then completely sealed by the rubber sealing rings.

The amount of steam-air mixture vented from each stage was able to be measured with orifice plates fitted to the vent lines (Fig. A3. 1).

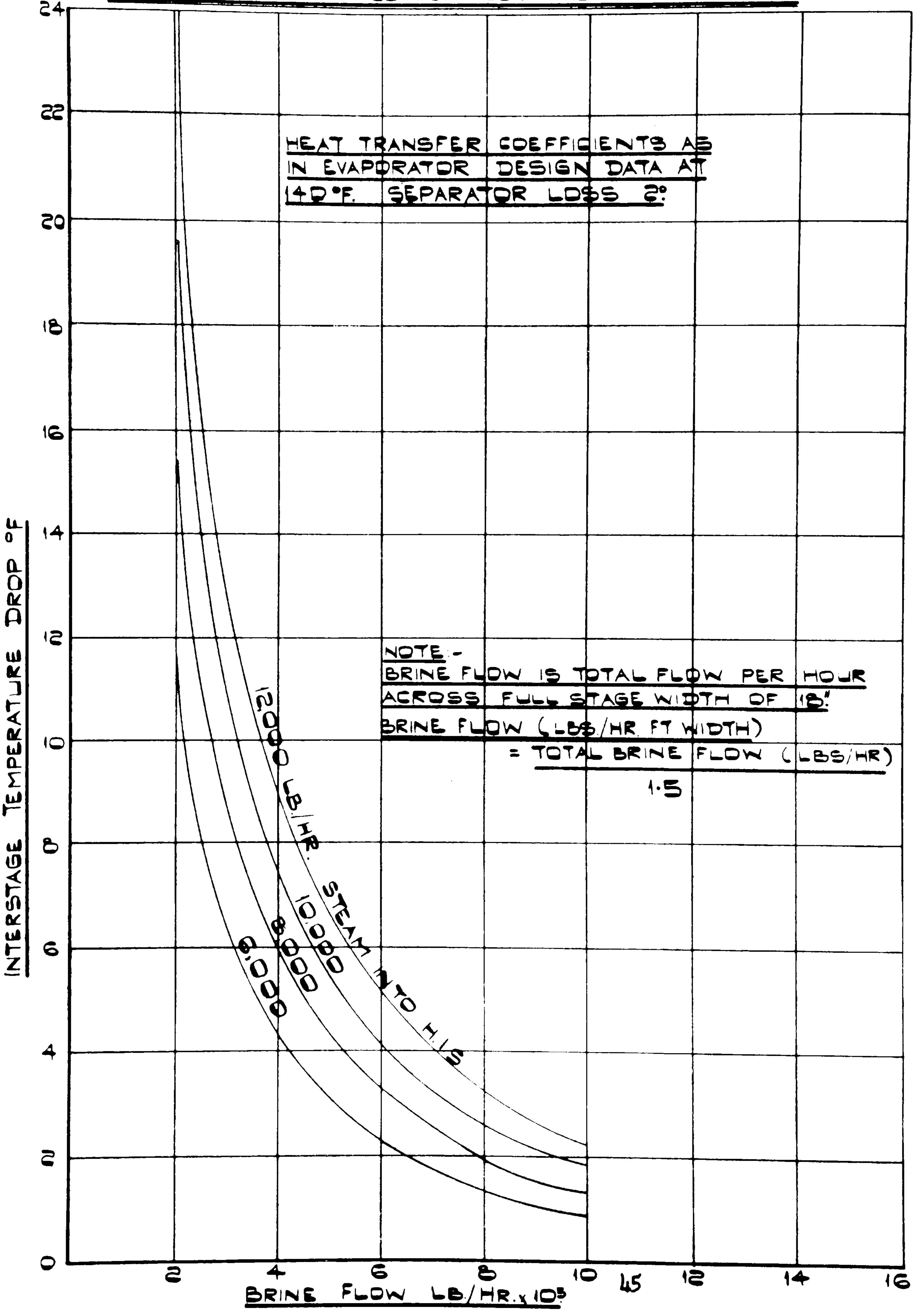
A1.5 Steam Supply

Heating steam from the factory mains is throttled down to a low pressure and desuperheated before it enters the heat input section. Steam supplies of up to 10,000 lbs/hr at a maximum pressure of 15 p.s.i.g. can be fed to the heater. The condensate is pumped back to the factory feed system. Control of the steam quantity is by either an automatic control valve or a manually operated gate valve.

A1.6 Performance

The maximum brine circulation which can be achieved is 1,000,000 lbs/hr and with lower brine circulations, interstage temperature drops of 8°F can be obtained (Fig. A1. 2). The plant can be run at brine temperature between 212°F and 90°F - thus covering the range normally met with in commercial evaporators. As the test plant is only a section of a complete commercial evaporator, it is not realistic to quote a figure for the performance of the plant unless the number of stages is scaled up to that which a complete evaporator would employ, working at the same temperature drop per stage as/

PERFORMANCE CURVES FOR TEST FACILITY - FIG A1.2



HEAT TRANSFER COEFFICIENTS AS IN EVAPORATOR DESIGN DATA AT 140°F. SEPARATOR LOSS 2°

NOTE:-

BRINE FLOW IS TOTAL FLOW PER HOUR ACROSS FULL STAGE WIDTH OF 18".

BRINE FLOW (LBS/HR FT WIDTH)

$$= \frac{\text{TOTAL BRINE FLOW (LBS/HR)}}{1.5}$$

as the test plant.

A1.7 Preflash Chamber

The circulating brine, after passing through the 4-pass steam-heated heat input section and the manual circulation control valve, enters the preflash chamber. This chamber eliminates any velocity effects and allows an even flow of brine to enter the first flash chamber. The brine depth in the preflash chamber can be varied by adjusting the brine transfer orifice into the first stage. The vapour space is vented to prevent the build-up of incondensible gases.

A1.8 Glass Windows

Each flash chamber is fitted with two 42" x 20" windows at both front and rear of the main vessel. Through them, the action of the flashing brine can be observed and brine levels and foam heights photographed for record purposes. Above the separators, two 20" x 20" windows are fitted at the front of the vapour space, and another 20" x 20" window at the rear.

A1.9 Interstage Brine Transfer Arrangements

Adjustable interstage brine transfer orifices are fitted to each stage division wall and allow the brine depth to be adjusted in each stage (see Fig. 4). A range of baffle and splash plate sizes can be fitted to match the flashing conditions in any test, but unlike the orifices, they cannot be adjusted while the plant is running.

A1.10/

A1.10 Splash Plates

To avoid direct impingement of flashing brine particles into the separator, "splash" plates are fitted above the interstage baffle arrangement. These plates are normally fixed horizontally to the interstage wall or in a slightly downward slope. A diagram of a typical splash plate is shown in Fig. 4.

A1.11 Instrumentation

Two groups of instruments are used in the test work. The first group is required for the running of the plant and indicates the general performance, while the second group are of a more temporary nature and will depend on the research being conducted. The first group indicate brine and vapour temperature, flow rates, purities, and pressures in the plant.

A1.12 Modifications Required for Research on Chamber Geometry

Certain modifications were required for the research work on chamber geometry. The more important modifications were:-

(1) Fitting a moveable wall in stage 3 of the test plant.

(2) Fitting a small condenser to stage 3.

(3) Fitting an extension box to stage 3.

(4) Installing a sensitive manometer to measure pressure on either side of the moveable wall.

(1) The Moveable Wall

For the purposes of the research, it was necessary to be able to vary the/

the length of one of the flash chambers. Thus, an extra wall was fitted to stage 3. This wall could be moved along the chamber from a minimum length to 18" to a maximum of 60". The adjustment of the wall could be made while the plant was running. Good sealing between the edges of the wall and the rough sides of the chamber was obtained by fitting a pneumatic seal which could be deflated to allow the wall to be moved along the chamber.

To allow the stage length to be reduced to a minimum of 18", part of the separator approach area was blanked off but this blanking plate could be removed in the cases where a large flash-off necessitated the use of the complete separator. In this case, the minimum stage length was then 32", but as the conditions of high flash-off required a long chamber length, the two conditions did not overlap.

Brine, after flashing in the first part of the chamber, was allowed to flow under the wall into the second part of the chamber. The distance between the bottom of the wall and the floor of the chamber could be varied to suit different conditions.

(2) Auxiliary Condenser

A small auxiliary condenser was required to condense steam from the downstream part of stage 3. This steam flowed along a 5" dia. duct and into the condenser (Fig. A1.1). To give flexibility of control, the condenser was mounted vertically so that by flooding the vessel with condensate, the surface area could be varied to give variable condensation rates. The cooling water rate could also be adjusted to give a fine control. The difficulties of venting/

venting such an arrangement was overcome by fitting venting points at different heights on the vessel and venting from the point immediately above the condensate level - the level being shown on a sight glass.

The rate of condensation was measured either in a positive displacement flow meter, or in the case of low rates of condensation, by closing the drain valve and timing a small rise in the condensate level.

(3) Stage 3 Extension Box

As some flashing was expected to take place on the downstream side of the moveable wall, the effective length of this part was increased by fitting an additional flash box in place of the interstage orifice. The box extended the chamber length by 12".

(4) Installation of a Sensitive Manometer in Stage 3

During the test work, it was required that the vapour pressures on either side of the moveable wall should be kept constant. Several attempts were made to install sensitive oil-on-water differential manometers but these proved to be unsatisfactory in practice. Finally, a plain vapour on water manometer was used with large bore tubes, and with proper shielding of the tapping points in the respective parts of the flash chambers, the required characteristics of accuracy and lack of oscillation were achieved.

APPENDIX 2

NOTES ON THE EXPERIMENTAL DATA

The experimental data obtained from the test work is re-printed in the Appendix to this report. To list the results, each parameter was allotted a series number - these are:-

Series 1 & 2	- Early tests improvements later made to equipment.
Series 3	- Variable brine circulation with a 22" high splash plate.
Series 4	- Variation in the brine circulation.
Series 5	- Variation in the interstage temperature drop.
Series 6	- Variation in the brine temperature.
Series 7	- Different brine transfer arrangements.
Series 8	- Variation in brine depth.
Series 11	- Variation in splash plate length and height.

Series 1 and 2 are not included. These were short tests which tended to have rather a large experimental error, and improvements in equipment and technique were made during and after the tests. Series 3 was discontinued because a large range of brine circulations could not be covered with the brine transfer/splash plate arrangement installed. Further improvements were made after this test also. Series 9 and 10 were designated to tests which were later included in Series 7 and 11.

Each/

Each separate test has been given a two part reference number. The first number gives the number of the test of that series, and the second gives the series number. These are shown in the first column in the tables of results. The second column gives the brine circulation in lbs/hr for each foot width of chamber. As the chamber was 18" wide, the actual brine circulation was 50% higher than the figure shown, but throughout this report it is the circulation per foot width which is referred to, unless otherwise stated.

The brine level given in column 3, is an approximate measurement. The level of brine is constantly fluctuating due to the boiling action, and during the test readings, the levels may change slightly. In all cases, except for Series 8 tests, the level aimed at was 12", but is generally slightly greater than this rather than slightly less, as a low brine level causes unsealing of the down-stream orifice.

The next column gives the overall temperature drop through the four stages. Mercury-in-glass thermometers in the brine ducting at entry and exit from the main vessel were used to measure the temperatures. Other temperature readings to show the temperature rise in the heat recovery section were also taken to verify the ΔT in the flash chambers but are not included here.

The brine temperature in stage 3 is given in column 5. This is followed by the temperature drop in stage 3 and is calculated from the total distillate/

distillate from the stage.

Columns 7 and 8 give the distillate from parts A and B of stage 3. These distillate quantities are produced by the total brine flowing through the chamber. The distillate from A also includes approximately 30 lbs/hr loss to venting, and another 20-30 lbs/hr is drawn off through the conductivity meter. The distillate from B is collected in the auxiliary condenser. As can be seen, this quantity is sometimes negative and gives an efficiency reading of over 100%. This is due to experimental error. During the test, the condensation rate in the auxiliary condenser is adjusted to make the pressure in both parts of the chamber equal. However, it is a practical impossibility to make both pressures exactly equal and the tendency was to make the B pressure slightly lower than the A pressure. This induced a slight extra flash-off in part B and increased the quantity of distillate collected in the condenser. The slight difference in pressure was noted and an allowance for this quantity was then subtracted from the B total to give the relative induced flash-off due to chamber inefficiency. Fig. A2.1 shows the calculated relationship between the difference in pressure between A and B, and the additional condensate in B. When the chamber is long and complete flash-off is being obtained in A, due to small errors in reading instruments, the flash-off calculated from Fig. A2.1 may be slightly greater than the quantity of distillate collected in the auxiliary condenser and the net result is a negative reading for flash-off in B.

To/

To investigate the relationship between the calculated induced flash-off in B and the quantity of condensate actually collected, the wall was set to give an "A" length of 60", and for a circulation of 200, 000 lbs/hr of brine per foot width, the condensation rate was varied. The results of this test are also shown on Fig. A2. 2. It can be assumed that the chamber is efficient at 60" and complete flash-off occurs in A.

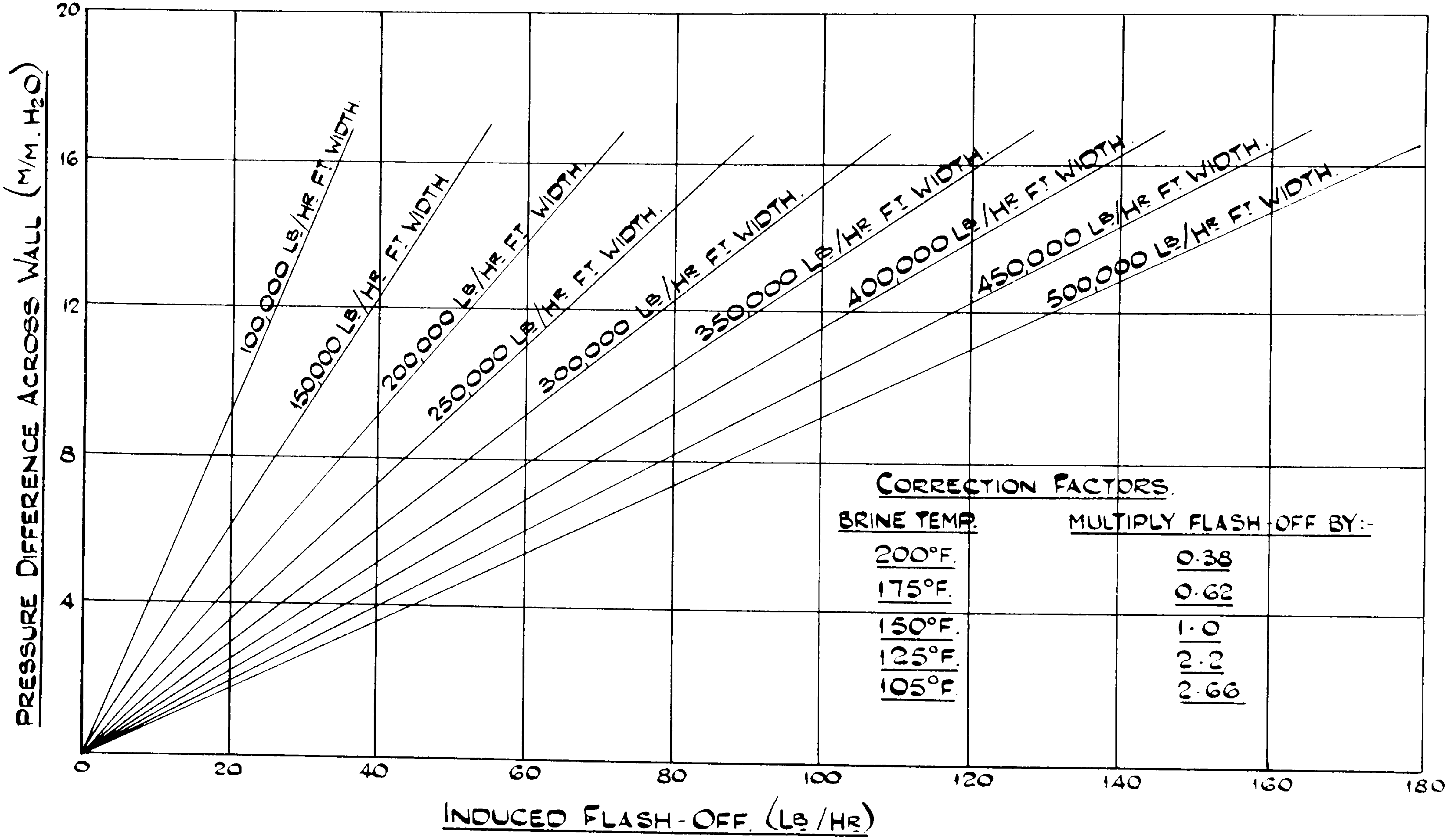
Obviously it requires only a small discrepancy in reading to obtain an apparent experimental error. This is especially noticeable when the efficiency is near 100%. It is thought that the error is approx. ± 1%. However, as the efficiency of the chamber falls, the condensation rate in the auxiliary condenser increases, and reduces the experimental error. Thus, importance is attached more to the slope of the curve, rather than the vague point where 100% efficiency is achieved. As a result, the point where 99% efficiency occurs is thought to be much more reliable and it is this 99% point which is used in the work for comparing different tests.

The stage 3 temperature drop shown in column 6 is the total distillate from A and B, but in the case of a negative quantity in B, this is taken as zero.

The last two columns in the table give the chamber efficiency and the corrected chamber length. The efficiency is calculated by:-

$$\eta_s = \frac{D_A}{D_A + D_B} \times 100\%$$

INDUCED FLASH - OFF DUE TO PRESSURE DROP AT 150°F. FIG: A.2.1.

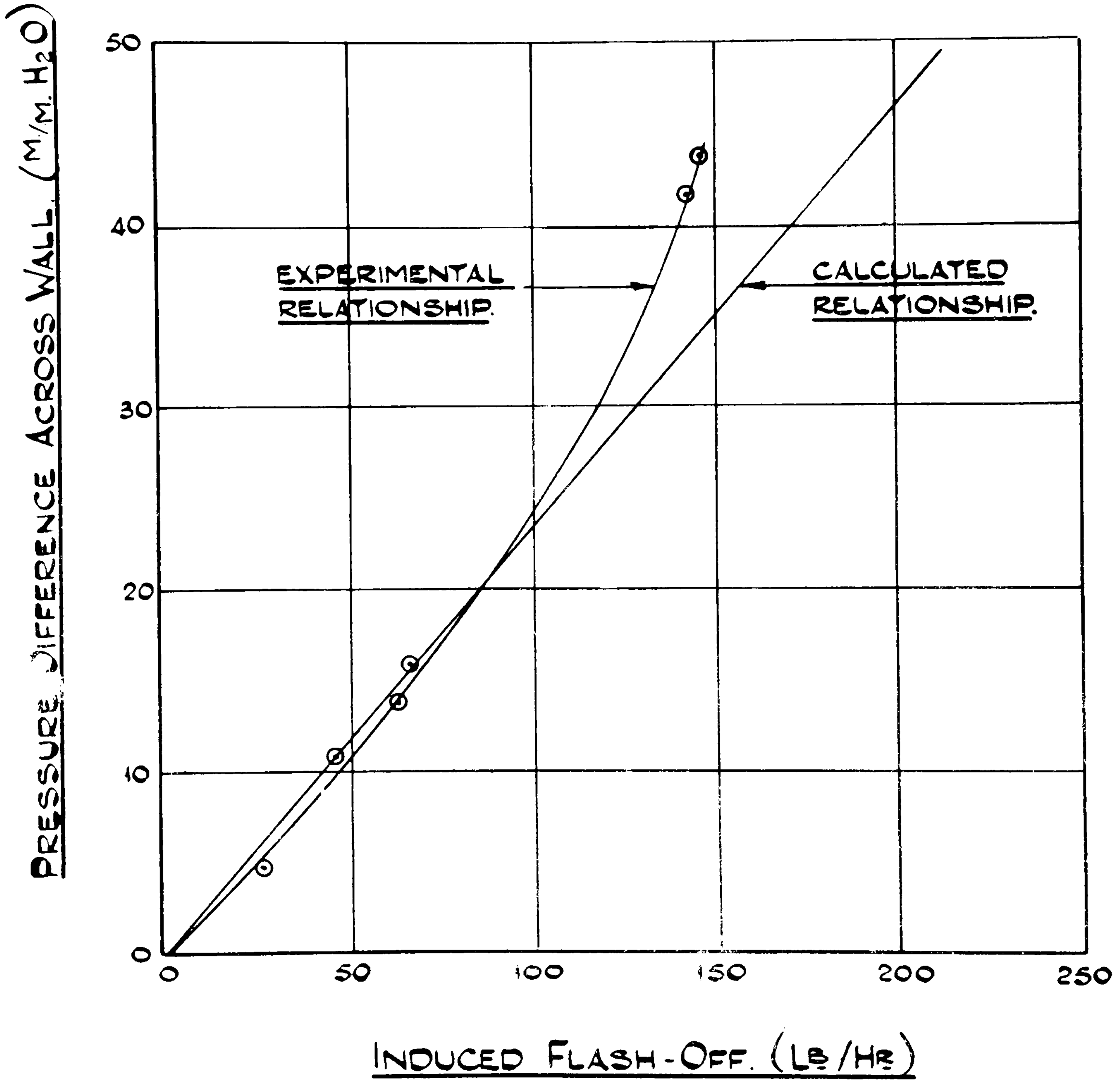


CORRECTION FACTORS.

BRINE TEMP.	MULTIPLY FLASH-OFF BY:-
200°F.	0·38
175°F.	0·62
150°F.	1·0
125°F.	2·2
105°F.	2·66

INDUCED FLASH-OFF DUE TO PRESSURE DIFFERENCE ACROSS WALL. FIG: A2.2

BRINE CIRCULATION — — — 200,000 LB/HR FT
BRINE TEMPERATURE — — — 150° F.
EFFECTIVE LENGTH OF 'A' — 60″



Departure from Research Programme

When the programme of work was drawn up, it was intended that information on the effect of chamber height on chamber efficiency should also be obtained. However, once the problem had been studied more closely and preliminary experimental work done, it became clear that the height of the flash chamber had no effect on the efficiency but that the length and height of the splash plate was important. Thus, the experimental work was done on splash plates instead of chamber heights.

Vapour/Brine Separators

Lowering the roof of the chamber increases the quantity of brine carried into the brine/vapour separators. The test plant used in the work was fitted with impact/centrifugal separators. The steam enters these separators at a relatively high velocity and is made to weave through a number of curved vanes and either of two things happen - (a) the steam approaching a vane must travel round it but the denser brine droplets travel straight on and collide with the vane and the liquid runs down into drainage channels, or (b) in other parts of the separator, the vanes are shaped to give the steam a rotational effect, in this case, the denser brine droplets are thrown out towards the sides of the vane and again are collected and drained away.

TABLE A2.1

SERIES 4 - EFFECT OF BRINE CIRCULATION ON CHAMBER LENGTH

Splash Plate - 10" long 32" high

Baffle Plate - 12" high 6" from orifice

Approx. Conditions - 200,000 - 500,000 at 150°F and 3° ΔT per Stage

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT (°F)	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
1/4	197,000	14	12.6	149.7	2.98	820	-17	102.1	31.0
2/4	200,000	12-14	12.4	150.0	2.88	794	-6	100.8	26.0
3/4	200,000	12-14	12.2	150.0	2.77	760	-13	101.7	23.5
4/4	200,000	12-14	11.9	151.6	2.68	710	29	96.1	19.5
5/4	200,000	13	10.6	152.4	2.60	696	21	97.0	21.8
6/4	200,000	12	12.5	150.4	3.12	858	-3	100.2	28.0
78/4	198,000	12-13	11.0	151.5	2.50	680	2	99.8	26.4
79/4	199,000	12	12.6	146.9	2.88	766	30	96.3	20.5
80/4	199,000	13	11.2	149.5	2.75	728	28	96.3	19.9
81/4	198,000	13	12.6	153.3	2.82	740	36	95.3	18.5
82/4	198,000	12	13.1	153.6	2.68	715	19	97.5	21.6
83/4	198,000	11-12	13.5	153.9	2.87	780	9	98.8	22.0
7/4	258,000	14	12.4	149.3	3.08	1050	-25	102.5	28.0
8/4	258,000	12-13	12.8	149.6	3.05	1038	-5	100.2	25.0
9/4	260,000	12	12.7	151.1	3.06	1000	42	96.0	23.0
10/4	260,000	12	11.1	150.5	2.68	866	48	94.7	21.6

TABLE A2.2

Test No.	Brine Circn. (lbs/hr. ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o}F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
11/4	260,000	13	11.7	151.6	2.95	1008	-16	101.5	31.5
13/4	260,000	13	11.5	149.5	3.00	1020	3	99.8	42.0
63/4	253,000	13½	12.0	151.5	3.05	1036	3	99.7	25.0
64/4	254,000	13	12.1	150.3	3.25	1050	52	95.3	23.0
65/4	253,000	13	11.8	148.6	3.15	1018	53	95.0	23.0
66/4	253,000	12	12.6	150.5	3.25	1105	-4	100.3	25.8
67/4	254,000	12	12.2	151.0	3.23	1064	35	96.9	24.0
68/4	254,000	12	12.5	151.4	3.29	1072	47	95.8	23.1
71/4	251,000	11-12	13.6	152.1	3.40	1165	2	99.8	25.2
72/4	250,000	13-14	12.8	153.5	2.90	990	-6	100.6	41.0
73/4	250,000	13	12.5	148.5	2.82	957	-2	100.2	24.0
74/4	250,000	12	12.1	153.4	2.73	925	5	99.4	23.6
75/4	250,000	12	12.8	151.7	2.83	923	42	95.6	22.5
76/4	250,000	12	12.4	151.2	2.68	860	55	94.0	22.7
77/4	250,000	12½	12.6	152.1	2.63	871	23	97.5	24.6
14/4	297,000	13	11.0	152.5	2.80	1160	0	100.0	43.1
16/4	297,000	13	13.7	147.3	3.40	1405	1	100.0	34.4
17/4	297,000	10-13	13.4	147.5	3.28	1355	0	100.0	61.0
18/4	297,000	12	12.9	147.4	3.05	1230	27	97.8	30.0
50/4	297,000	13	12.1	150.0	3.27	1330	-14	101.1	36.4
51/4	297,000	13	12.0	148.5	3.27	1330	-6	100.4	34.5

TABLE A2.3

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o}F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
52/4	297,000	$13\frac{1}{2}$	12.1	148.6	2.98	1230	-9	100.7	31.0
53/4	297,000	$13\frac{1}{2}$	11.4	149.6	3.40	1380	20	98.5	26.0
54/4	300,000	$13\frac{1}{2}$	11.8	150.2	2.87	1130	52	95.6	26.6
30/4	350,000	15	12.5	148.7	3.27	1535	33	98.0	37.8
31/4	350,000	13	11.2	148.5	3.12	1445	42	97.3	37.0
32/4	350,000	13.5	11.6	148.1	3.15	1470	44	97.1	35.0
33/4	350,000	13-14	12.1	151.9	2.82	1295	52	96.1	32.7
43/4	350,000	12-13	11.8	151.2	3.13	1455	39	97.3	36.0
44/4	350,000	14	12.5	149.3	3.06	1430	34	97.6	34.0
47/4	350,000	14	12.0	151.0	3.10	1455	26	98.2	36.5
48/4	350,000	14	11.7	149.8	3.07	1455	13	99.2	40.5
49/4	350,000	14	11.2	149.3	3.07	1455	11	99.3	46.0
55/4	349,000	13-14	12.0	150.1	3.20	1525	7	99.5	48.0
56/4	350,000	12-13	11.5	151.1	3.13	1500	-6	100.3	41.0
57/4	350,000	12-13	12.2	151.5	3.08	1470	5	99.6	39.0
58/4	350,000	13-14	12.0	151.5	2.98	1418	8	99.5	36.5
59/4	350,000	13-14	12.0	151.6	2.98	1412	10	99.3	35.0
60/4	350,000	13	12.0	151.5	2.95	1390	22	98.4	33.0
61/4	350,000	13	11.8	150.7	2.69	1235	50	96.1	32.2
62/4	350,000	13	11.5	151.0	2.93	1390	17	98.8	34.0

TABLE A2. 4

Test No.	Brine Circn. (lbs/hr. ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
84/4	346,000	13	12.5	152.7	2.78	1300	30	97.8	33.9
85/4	346,000	14	12.0	150.0	2.69	1240	48	96.3	32.2
86/4	345,000	15	11.6	149.5	2.67	1230	51	96.0	30.1
87/4	345,000	13-14	12.0	149.5	2.95	1390	21	98.6	34.5
26/4	400,000	13	11.9	150.6	3.25	1765	21	98.9	51.3
27/4	400,000	14	13.4	152.1	2.98	1615	22	98.7	44.0
28/4	400,000	15	12.7	149.9	2.64	1385	61	95.8	38.6
29/4	400,000	14	12.6	150.4	2.97	1610	21	98.6	41.5
34/4	400,000	12	12.0	151.1	3.25	1780	3	99.8	52.5
35/4	397,000	13-14	12.4	152.2	3.01	1635	18	98.9	46.0
36/4	397,000	14	12.2	151.4	2.86	1645	32	98.1	43.8
37/4	397,000	14-15	11.0	150	3.15	1675	58	96.6	39.4
38/4	397,000	13	12.6	150.2	3.19	1725	24	98.7	41.0
39/4	397,000	13	11.2	150.3	3.17	1710	28	98.5	45.0
100/4	440,000	12	15.4	173.5	3.01	1844	5	99.8	58.3
101/4	441,000	14	11.8	176.2	2.96	1792	31	98.3	44.8
102/4	440,000	14.5	12.5	176.5	3.17	1898	33	97.1	42.1
103/4	441,000	15	11.0	174.5	2.63	1511	84	94.7	43.6
104/4	439,000	15.5	12.3	176.5	3.01	1758	93	94.9	40.1

TABLE A2.5

Test No.	Brine Circn. (lbs/hr/ft)	Brine Level (Ins)	Overall Δ T °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate		Stage Effic. (%)	Chamber Length (Ins)
						A (lbs/hr)	B (lbs/hr)		
105/4	501,000	14	19.5	179.5	3.30	2220	9	99.6	54.3
106/4	500,000	14	20.2	179.3	3.45	2340	6.5	99.7	64.0
107/4	501,000	14	16.6	178.2	3.00	2006	45	98.0	55.4
108/4	500,000	14	16.4	181.5	2.85	1925	49	97.5	54.1
109/4	501,000	14	16.8	181.0	3.15	2120	45	97.9	49.5
110/4	502,000	12	16.5	182.6	3.20	2170	43	98.2	49.3
111/4	503,000	14	16.3	182.6	2.95	1985	51	97.6	48.4
112/4	503,000	14	16.5	183.2	2.95	1947	50	97.5	46.0
113/4	502,000	14	16.8	183.4	2.85	1925	49	97.5	45.5
114/4	502,000	14.5	17.3	183.5	2.70	1765	99	94.7	44.8
115/4	501,000	13.5	16.8	181.6	2.95	1925	66	96.7	43.7
116/4	499,000	13.5	15.7	184.5	2.85	1925	35	98.3	54.8

NOTE 1 The above experimental data is plotted on Fig. 6

NOTE 2 Tests 100/4 to 116/4 were conducted with the baffle set at 9" from the first orifice and the brine temperature from 170°-185°F. The chamber lengths have been corrected to give the equivalent lengths at 150°F.

TABLE A2.6

SERIES 5 - EFFECT OF INTERSTAGE TEMPERATURE DROP

General Conditions

Brine Circulation - 250,000 lbs/hr at 150°F

Baffle Dimensions - 12" high, 6" from 1st orifice

Splash Plate Dimensions - 10" long, 32" high

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
TEMPERATURE DROP -1.8°F per stage									
1/5	253,000	13	8.7	149.5	2.18	738	1.5	99.8	31.5
2/5	253,000	13	8.5	148.0	2.31	785	-4	100.5	27.0
3/5	250,000	13	8.0	150.5	1.50	505	35	93.5	21.0
4/5	252,000	12	8.2	149.6	1.70	573	-1	100.1	23.5
5/5	252,000	12	7.8	150.7	1.98	668	-5	100.7	29.5
6/5	252,000	12	8.0	151.5	1.68	564	15	97.4	22.0
7/5	252,000	12	7.7	150.1	1.73	590	10	98.3	22.5
8/5	250,000	12	7.9	149.1	1.82	616	2	99.8	23.0
TEMPERATURE DROP -3.3°F per stage									
9/5	247,000	13	16.5	152.7	2.90	848	134	86.4	23.5
10/5	253,000	13	16.4	151.0	3.60	1202	24	98.1	26.5
11/5	253,000	12-13	16.1	151.4	3.15	1010	64	94.0	25.2
12/5	254,000	12-13	15.5	151.5	3.27	1055	57	94.8	26.0
13/5	254,000	12.5	16.0	151.5	3.22	1094	-4	100.3	27.0

TABLE A2.7

Test No.	Brine Circn. (lbs/hr. ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
TEMPERATURE DROP -5.7°F per stage									
18/5	250,000	12.5	23.9	151.0	5.7	1945	8	99.5	35.5
19/5	248,000	12.5	24.3	150.6	5.7	1945	-2	100.1	37.7
20/5	247,000	15.0	23.1	148.6	5.73	1945	16	99.2	42.0
21/5	254,000	12	23.8	148.7	5.55	1880	20	99.0	48.0
22/5	254,000	13.5	25.0	148.8	5.50	1860	23	98.8	41.0
23/5	254,000	12	25.7	148.9	6.0	2050	25	98.6	35.0
24/5	248,000	13	24.6	149.0	6.0	2050	61	97.1	28.7
25/5	250,000	13	24.7	149.1	6.0	2050	135	93.7	26.5
TEMPERATURE DROP - 8°F per stage									
27/5	258,000	13	-	153.3	8.5	3032	26.4	99.4	47
28/5	264,000	13	-	149.5	8.2	2910	59.5	98.1	42
29/5	248,000	14	-	153.7	8.2	2830	69.3	97.7	40

NOTE 1: The above experimental data is plotted on Fig. 8., together with tests 7/4 - 13/4 and 63/4 - 77/4 for an interstage temperature drop of 3°F.

NOTE 2: The temperature drop in stage 3 for tests at 5.7°F and 8°F is approximate only, as drops of brine were being carried through the the separator by the high steam velocities and slightly increasing the apparent distillate output, from which the interstage temperature drop is calculated. (See Section 6.4).

TABLE A2.8

SERIES 6 - EFFECT OF BRINE TEMPERATURE

Splash Plate - 10" long, 32" high

Baffle Plate - 12" high, 6" from 1st orifice

Approx. Conditions - 300,000 lbs/hr at 3°F Δ T per stage

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall Δ T °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
Brine Temperature - 200°F									
1/6	304,000	12-13	12.2	199.9	2.92	1189	13	98.8	25.2
3/6	302,000	13	12.5	201.5	2.84	1123	44	96.4	23.4
5/6	299,000	13	12.4	199.0	2.79	1149	-6	100.4	30.8
6/6	298,000	13	13.0	197.5	3.21	1250	77	94.3	22.5
7/6	297,000	13	13.3	197.7	3.29	1144	212	84.5	21.5
Brine Temperature - 175°F									
8/6	295,000	13	13.3	177.2	3.53	1450	3	99.8	28.4
9/6	295,000	13	13.4	175.1	3.08	1250	16	98.8	26.0
10/6	298,000	13	12.4	178.0	2.65	1062	31	97.2	25.4
11/6	298,000	14	12.1	170.7	2.80	1062	95	92.0	24.0
Brine Temperature - 125°F									
12/6	304,000	13-14	13.1	126.6	3.45	1424	-22	101.6	38
13/6	299,000	13	13.1	126.6	3.42	1409	-23	101.6	34.4
14/6	293,000	13	13.0	124.0	3.11	1274	7	99.5	33.6
15/6	297,000	13	12.5	122.0	3.16	1279	23	98.3	31.0
16/6	300,000	14	12.6	125.5	3.05	1235	23	98.2	30.3

TABLE A2.9

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o}F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
Brine Temp. - 125 ^{o}F (Cont'd)									
17/6	300,000	14	13.0	126.0	3.06	1230	32	97.3	28.7
18/6	299,000	14	13.0	126.2	2.97	1145	80	93.5	27.1

NOTE 1: The above experimental data is plotted on Fig. 10, together with tests 14/4 - 18/4 and 50/4 - 54/4 at 150^{o}F.

Other Tests at Low Temperatures

Baffle plate 6" high 12" from 1st orifice - Splash plate 10" long, 32" high.

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o}F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
19/6	242,000	13	14.0	99.0	3.32	1114	16	98.6	47
20/6	242,000	13	14.0	98.5	3.29	1102	20	98.2	44.2
21/6	242,000	13	15.4	99.5	3.70	1242	25	98.0	38.8
22/6	242,000	13	14.0	96.5	3.30	1073	53	95.3	36.7
23/6	242,000	13	15.0	99.1	3.72	1212	59	95.4	34.2
24/6	242,000	13	15.7	100.1	3.81	1233	67	94.8	32.2

Baffle plate 12" high 9" from 1st orifice - Splash plate 5" long, 32" high.

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o}F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
30/6	254,000	15	11.5	108.7	3.02	936	95	90.8	25.0
31/6	254,000	15	10.4	109.8	2.96	936	72	92.9	26.0
32/6	254,000	15	11.2	108.2	3.05	992	43	95.8	29.0
33/6	252,000	15	11.5	109.1	3.23	1060	34	96.9	30.3
34/6	252,000	15	13.0	109.5	3.30	1085	32	97.1	31.9
35/6	252,000	15	12.3	110.2	3.65	1220	25	98.0	32.7
36/6	252,000	15	11.5	108.5	3.27	1090	22	98.0	36.2
37/6	252,000	15	11.0	108.0	3.23	1080	17	98.4	39.9
38/6	252,000	15	10.9	108.9	3.38	1140	13	98.9	43

TABLE A2.10

Test No.	Brine Circn. (lbs/hr. ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 4 (°F)	Temp. Drop Stage 3 (°F)	Distillate		Stage Effic. (%)	Chamber Length (Ins)
						A (lbs/hr)	B (lbs/hr)		
Baffle plate 6" high 12" from 1st orifice - Splash plate 10" long, 32" high.									
25/6	199,000	13	14.9	100.0	3.53	973	-6.2	100.6	48.7
26/6	199,000	13	17.3	100.0	3.87	1063	4.6	99.6	29.4
27/6	199,000	13	17.3	102.7	3.85	1039	24	97.7	27.6
28/6	199,000	13	16.1	102.4	3.75	1004	29	97.2	27.0
29/6	199,000	13	18.6	106.0	3.98	1056	43	96.1	25.2

NOTE 2: The above experimental data is plotted on Figs. 11 and 12.

TABLE A2.11

SERIES 7 - EFFECT OF BRINE TRANSFER ARRANGEMENT ON CHAMBER LENGTH

General Conditions - 300,000 lbs/hr. at 150°F with 3° Δ T per stage

Splash Plate - 10" long, 32" high.

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
BAFFLE - 12" high, 9" from 1st Orifice									
1/7	298,000	12	12.5	149.5	3.37	1380	3	99.7	31.6
2/7	298,000	12	12.5	149.1	3.19	1305	16	99.0	29.4
3/7	298,000	12	12.5	149.1	3.24	1305	29	97.8	27.3
4/7	298,000	12	12.1	148.9	3.07	1220	45	96.5	26.8
5/7	298,000	12	12.9	149.1	3.04	1225	29	97.6	28.4
6/7	296,000	11	12.7	149.9	3.18	1272	40	97.0	28.0
7/7	296,000	11.5	12.4	149.3	3.09	1252	23	98.3	28.7
BAFFLE - 12" high, 3" from 1st Orifice									
13/7	294,000	12	13.2	150.6	3.41	1403	-3	101.0	32.4
14/7	294,000	13	11.5	151.5	2.69	1095	13	99.0	30.5
15/7	294,000	13	12.2	151.3	2.71	1065	48	94.2	29.4
16/7	294,000	13	12.7	152.0	2.85	1164	10	99.0	30.5
17/7	294,000	13	12.4	149.1	3.09	1260	11	99.0	30.7
BAFFLE - 6" high, 12" from 1st Orifice									
18/7	298,000	14	12.6	150.6	3.22	1311	15	99.0	36.0
19/7	296,000	13	12.7	150.8	3.26	1327	17	98.6	34.9

TABLE A2.12

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT ^{o}F	Brine Temp. Stage 3 (^{o} F)	Temp. Drop Stage 3 (^{o}F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
Baffle - 6" high, 12" from 1st Orifice (Cont'd)									
20/7	296,000	14	13.1	150.5	3.13	1269	20	98.5	34.5
21/7	293,000	14	12.5	147.3	2.84	1164	6	99.6	40.8
22/7	297,000	14	12.3	146.7	2.94	1192	23	98.2	37.3
23/7	296,000	14	11.9	146.3	2.84	1132	35	97.3	35.7
24/7	296,000	14	12.5	146.5	2.75	1094	46	96.1	34.7

NOTE 1: The above experimental data is plotted on Fig. 14, together with tests 14/4 - 18/4 and 50/4 - 54/4 for a 12" high baffle, 6" from the 1st orifice.

TABLE A2.13

SERIES 8 - EFFECT OF BRINE LEVEL ON CHAMBER LENGTH

Splash Plate - 10" long, 32" high.

Baffle Plate - 12" high, 9" from Orifice

Approx. Conditions - 300,000 lbs/hr. at 150°F with 3° ΔT per stage

Test No.	Brine Circn. (lbs/hr. ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
1/8	299,000	15	11.1	151.1	2.94	1200	7.5	99.5	29.8
2/8	299,000	15	12.1	152.5	2.75	1126	8.6	99.1	29.9
3/8	299,000	15	12.7	152.8	2.72	1108	14.8	98.5	29.4
4/8	299,000	15	12.1	152.0	2.7	1090	25.9	97.7	29.0
5/8	299,000	15	12.0	151.5	2.75	1075	57.5	94.9	28.3
6/8	299,000	15	12.0	151.6	2.84	1162	6.6	99.6	32.1
7/8	299,000	15	12.2	151.6	2.77	1143	-5.0	100.4	35.0
8/8	298,000	18	12.0	152.6	2.48	1022	0	100	38.6
9/8	298,000	18	11.9	152.2	2.57	1060	2.4	99.7	33.8
10/8	299,000	18	10.7	151.8	2.8	1147	8.6	99.2	31.8
11/8	299,000	18	12.0	149.2	2.82	1120	43.5	96.1	30.9
12/8	298,000	23	12.0	150.0	2.86	1180	0	100	45.9
13/8	299,000	22.5	12.8	148.4	2.89	1190	0	100	39.8
14/8	299,000	22	13.0	149.3	2.63	1079	2.7	99.5	38.8
15/8	299,000	22.5	12.9	149.9	2.8	1139	12.1	98.8	36.6
16/8	299,000	22	13.0	150.1	2.89	1147	41.5	96.5	35.0

NOTE 1: The above experimental data is plotted on Fig. 15, together with tests 1/7 - 7/7 for a 12" brine level.

TABLE A2.14

SERIES 11 - EFFECT OF SPLASH PLATE ON CHAMBER LENGTH

General Conditions - 250,000 and 300,000 lb/hr at 150°F and 3° ΔT per stage.

Baffle Plate - 12" high, 6" from 1st Orifice

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate A (lbs/hr)	Distillate B (lbs/hr)	Stage Effic. (%)	Chamber Length (Ins)
SPLASH PLATE - 5" long, 32" high									
33/11	294,000	13	13.1	152.4	3.80	1385	8.5	99.4	29.2
34/11	295,000	13	10.5	150.0	2.50	1090	7.0	99.5	34.0
35/11	295,000	14.5	12.6	147.9	2.40	1040	28	97.5	30.2
36/11	295,000	16	13.4	146.7	3.00	1275	66	95.0	26.0
37/11	277,000	13	12.2	149.5	2.45	1054	14	99.0	26.6
38/11	279,000	13	11.8	157.4	2.20	1002	21	97.9	26.8
39/11	279,000	13	11.8	154.0	2.25	977	52	94.9	25.6
40/11	280,000	13	11.7	154.5	2.35	1013	28	97.4	24.9
41/11	280,000	13	12.5	154.5	2.50	1085	15	98.7	27.4
SPLASH PLATE - 15" long, 32" high									
1/11	295,000	11	13.7	149.6	2.86	1160	13	98.9	33.5
2/11	305,000	12.5	13.7	149.4	3.07	1220	42	96.7	31.0
3/11	303,000	12	13.0	150.5	2.85	1120	53	95.4	30.2
4/11	303,000	12	12.7	150.3	2.96	1180	41	96.8	30.5
5/11	303,000	12	12.7	150.3	3.05	1225	28	97.8	31.7
6/11	304,000	12	12.7	151.0	3.09	1250	26	99.0	34.5
7/11	304,000	12	13.3	151.1	3.08	1245	24	99.3	37.0
8/11	304,000	12	13.4	150.1	3.25	1310	22	99.8	40.6
9/11	303,000	12	12.3	148.7	3.00	1215	23	98.3	49.0

TABLE A2.15

Test No.	Brine Circn. (lbs/hr.ft)	Brine Level (Ins)	Overall ΔT °F	Brine Temp. Stage 3 (°F)	Temp. Drop Stage 3 (°F)	Distillate		Stage Effic. (%)	Chamber Length (Ins)
						A (lbs/hr)	B (lbs/hr)		
SPLASH PLATE - 10" long, 27" high									
20/11	257,000	12.5	12.5	150.5	2.74	895	35	96.4	28.8
21/11	256,000	13	13.2	149.9	2.95	850	157	85.4	26.5
22/11	257,000	11.5	13.1	150.6	2.83	930	33	96.7	29.0
23/11	257,000	13	12.3	150.7	2.67	840	68	93.0	28.6
24/11	258,000	12.5	12.7	150.5	2.86	975	3	99.8	31.0
25/11	258,000	13	13.2	152.8	2.71	915	7	99.3	30.6
26/11	258,000	13	13.0	152.1	3.12	1065	-2	100.1	34.5
27/11	258,000	13	11.7	151.8	2.87	980	-2½	100.2	41.8
SPLASH PLATE - 10" long, 22" high									
36/3	250,000	14	12.5	151.1	2.5	761	83	90.2	25.3
37/3	250,000	14.5	12.0	152.2	2.3	758	24	96.9	29.4
38/3	250,000	14.5	12.0	151.5	2.75	900	15	98.4	29.8
39/3	249,000	15	12.0	151.0	3.04	1036	-3	100.1	41.0
40/3	249,000	15	12.0	150.0	3.2	1075	12	99	48.0
41/3	249,000	15	12.7	147.5	3.3	1128	-2	100.1	58.0
42/3	249,000	15	11.9	149.6	3.06	1020	22	97.8	36.0

NOTE 1: The experimental data from tests 33/11 - 41/11 and 1/11 - 9/11 is plotted on Fig. 18, together with tests 14/4 - 18/4 and 50/4 - 54/4 for a 10" long splash plate, 32" high.

NOTE 2: The data from tests 20/11 - 27/11 and 36/3 - 42/3 is plotted on Fig. 17, together with tests 7/4 - 13/4, 63/4 - 77/4 for a 10" long splash plate, 32" high.

APPENDIX 3

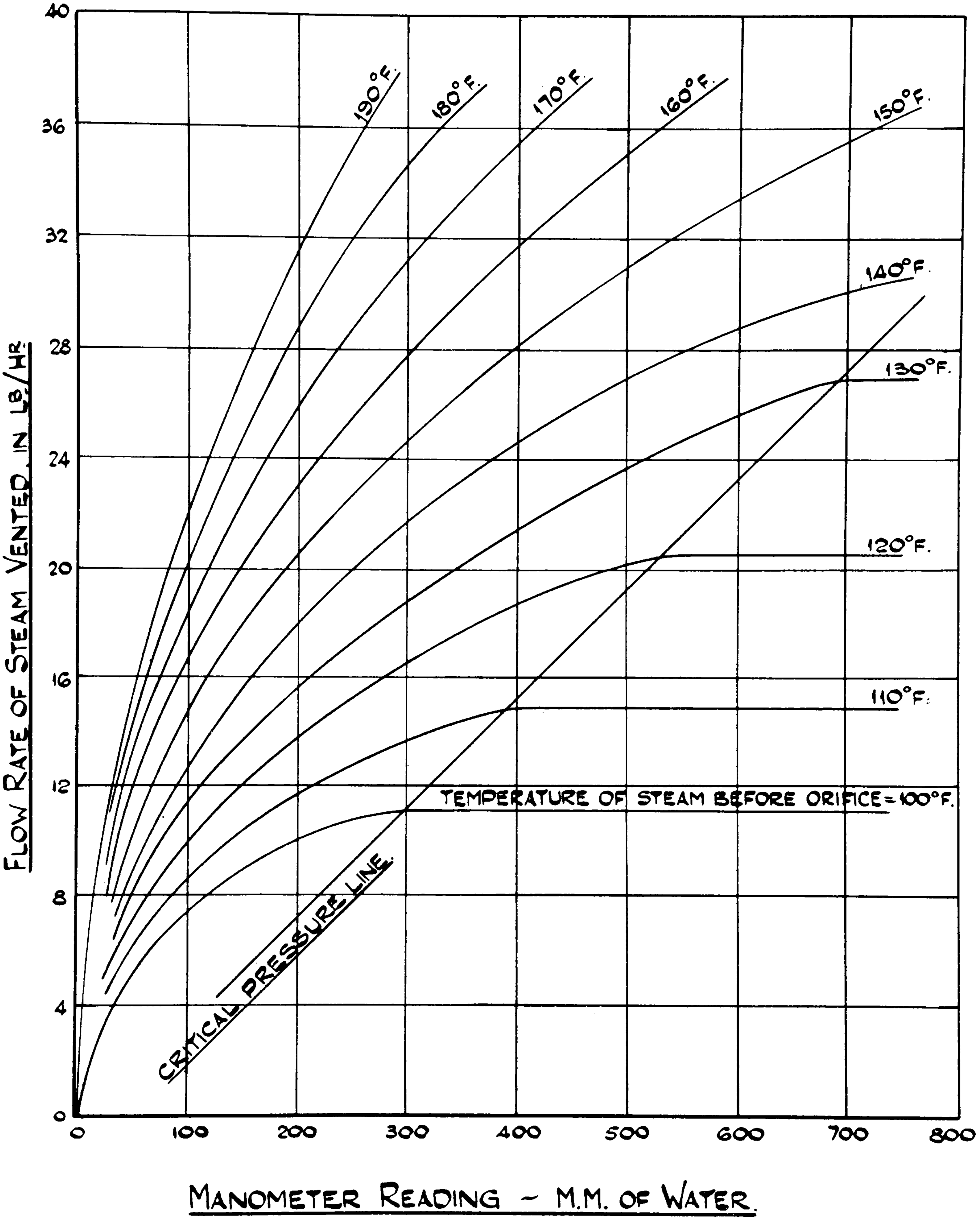
VENTING TEST

As mentioned in Appendix 1, the heat recovery section was originally vented from stage to stage through the clearances in the interstage tube support plates, giving series venting. As the air leakage into each stage was unequal, due to the large joint length in each stage and the numerous tapping points for instruments, difficulty was found in running all four stages at equal rates of flashing. Hence, the series venting was later changed to parallel venting to give equal flash-off in each stage.

The modified system was not ideal because the steam - air mixture was then vented from the rear of the tube bundle but it did give the required control. After start-up, the controls in the plant were adjusted until the approximate conditions were achieved. The distillate quantities from each stage were then measured. Comparison of these quantities showed any stage which was not producing the required output. Adjusting the vents slightly generally gave the required constant flash-off in each stage. The quantity vented from each stage was measured by an orifice plate, and manometer, in each vent line. A conversion curve to enable the vent flows for a range of temperatures to be estimated is shown in Fig. A3.1.

To investigate the effectiveness of increasing the rate of venting from each stage, the test evaporator was run at steady conditions of temperature/

VENTED STEAM CONVERSION CURVES. FIG: A.3.1.



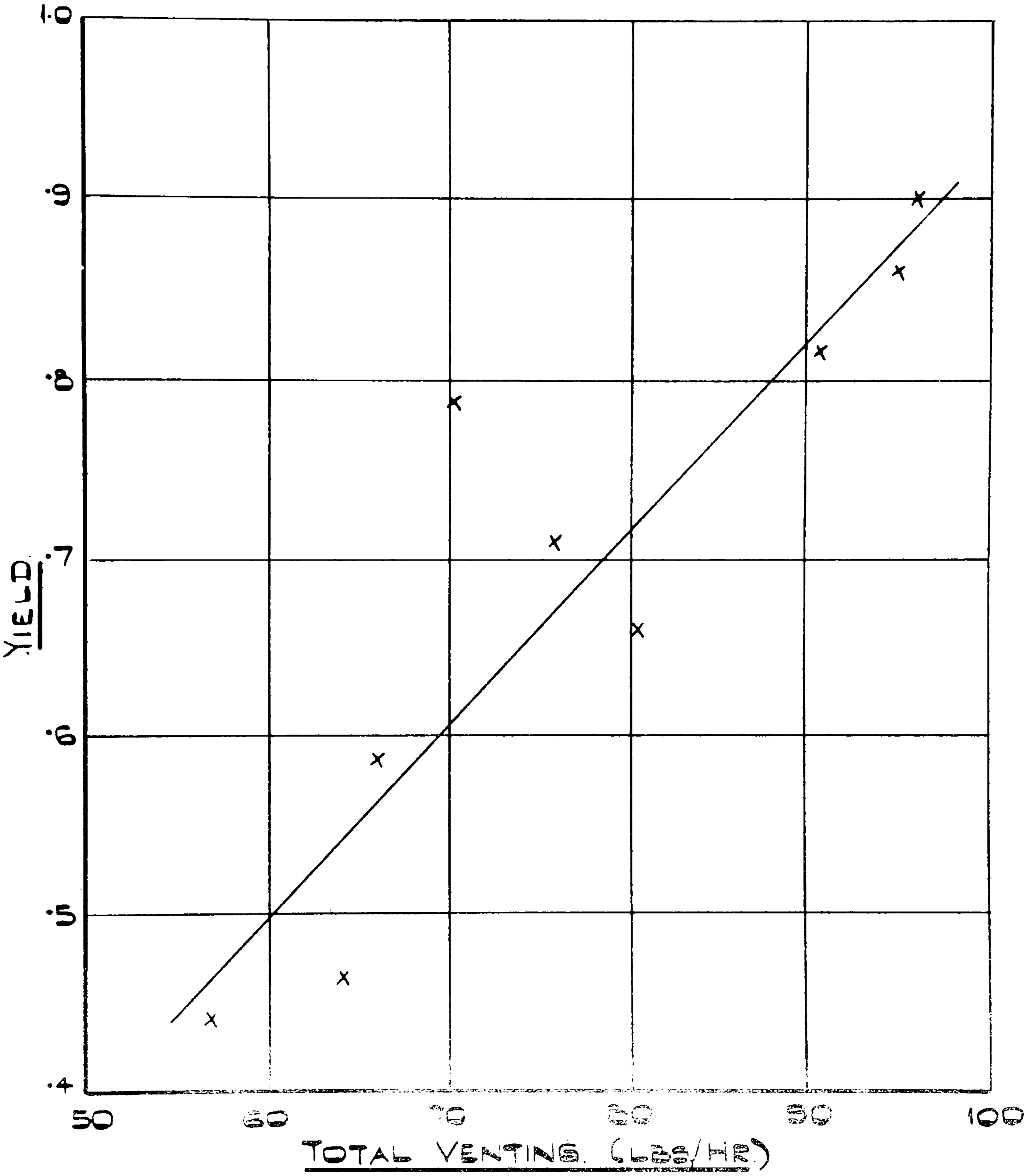
temperature and circulation, and the rate of venting gradually increased. Measurements were taken of distillate quantities and vented steam quantities for each different rate of venting. A summary of the results is shown in Table A3.1, and a curve of yield to a base of vented steam quantity was drawn - Fig. A3.2. For the tests, the length of stage 3A was set at its maximum length and the stage remained at 100% efficiency throughout.

The curve shows the expected increase in yield with higher venting but there is no indication for the range covered of a maximum yield. It is suggested that improvement in efficiency with high vent flows is due to two factors:

1. Air, or non-condensable gases, collect in the centre and at the rear of the tube bundle. Increasing the vent flow will remove the non-condensables at the rear of the bundle.
2. The condensing steam is drawn across the tubes in greater quantities and reduces stagnation at the rear of the bundle as well as preventing air build-up in the centre.

During the tests, the heating steam, cooling water, and circulating brine rates, were kept approximately constant and the flash range was allowed to increase. However, as the research vehicle is only part of an evaporator, the flash range is restricted to only four stages and thus the "yield" - the ratio of distillate produced to heating steam required - is low, the maximum value being/

INCREASE IN PERFORMANCE DUE TO BETTER VENTING FIG. A3 2



BRINE CIRCULATION :- 380,000 - 400,000 LBS./HR.

BRINE TEMP.:- -------- 150°F.

OVERALL ΔT :- -------- 7·2 - 15°F

YIELD = LBS. DISTILLATE PRODUCED / LBS. STEAM TO HT. INPUT SECTION.

being only 0.902 to 1. However, working over the normal flash range of 80°F instead of only 15.4°F would give an effective yield of 5.2 (assuming that the number of stages was increased in proportion).

The distillate produced was measured directly and an estimate was also calculated from the temperature rise in the heat recovery section. The mean of the two distillate quantities was used in the estimation of the yield.

As there were many differences between the venting arrangements on the research vehicle and those on a commercial evaporator, it was decided that further testing would not give information which was of value in design work, and thus the tests were confined to those which demonstrated the importance of adequate venting in a multistage flash evaporator.

Conclusions

Increasing the rate of venting in the test evaporator showed an improvement in the thermodynamic performance of the plant. However, as the evaporator is not typical of a commercial plant for the several reasons mentioned above, the results do not contain data which can be used for commercial design.

Definition

The "Yield" or "Performance Ratio" of a flash evaporator is defined as the weight ratio of distillate produced to heating steam supplied with a useful heat content of 1,000 B.T.U/lb.

TABLE A3.1

RESULTS OF VENTING TEST

Test No.	Brine Circulation lb/hr	Est. Steam Conspt. lb/hr	ΔT in H.R.S. °F	Equiv. Dist. lb/hr	Actual Dist. lb/hr	Mean Dist. lb/hr	Vented Steam lb/hr	Yield
V/1	375,000	5,220	6.2	2,160	2,454	2,307	57.1	0.442
V/2	375,000	5,580	7.3	2,540	2,732	2,636	64.3	0.464
V/3	370,000	5,680	9.8	3,370	3,299	3,334	66.1	0.587
V/4	405,000	6,480	11.5	4,330	4,215	4,273	80.7	0.660
V/5	395,000	6,530	13.0	4,770	4,476	4,623	76.0	0.709
V/6	395,000	5,940	13.2	4,850	4,328	4,589	70.4	0.789
V/7	394,000	5,900	13.5	4,960	4,680	4,820	90.9	0.817
V/8	400,000	5,780	14.8	5,510	4,455	4,982	95.0	0.862
V/9	403,000	6,100	15.4	5,780	5,220	5,500	96.1	0.902

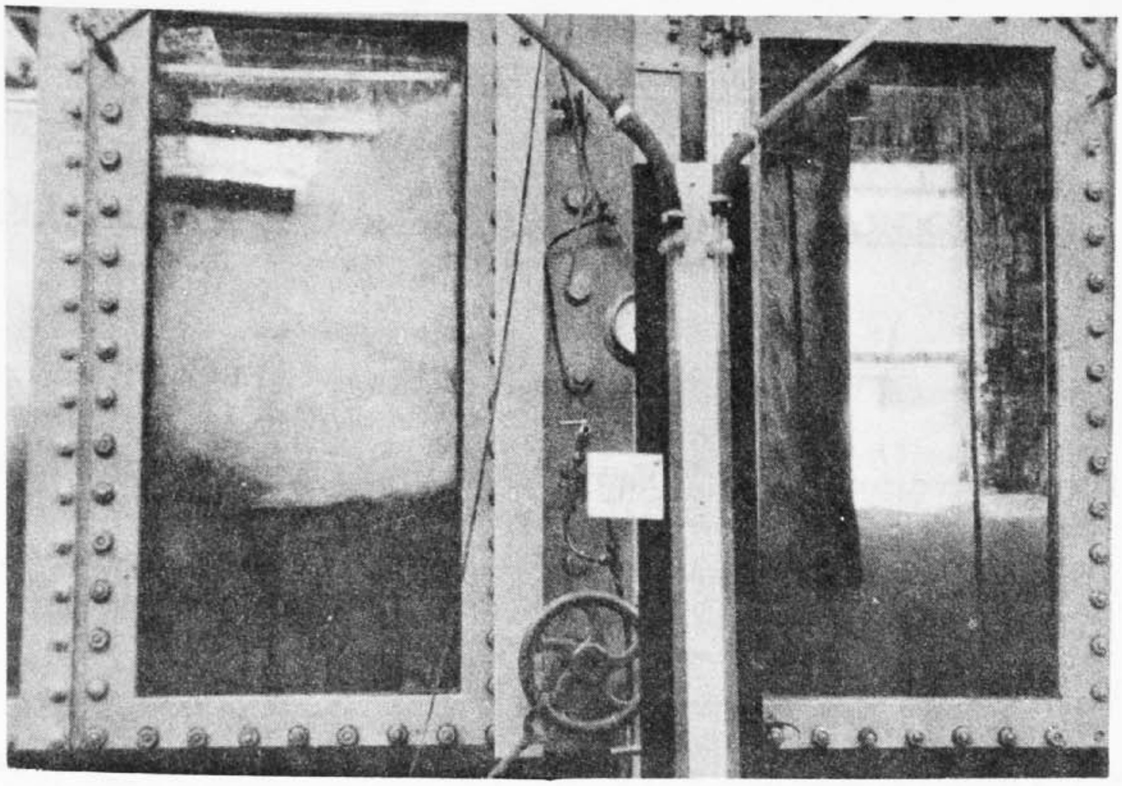
APPENDIX 4

PHOTOGRAPHIC RECORD OF FLASHING CONDITIONS

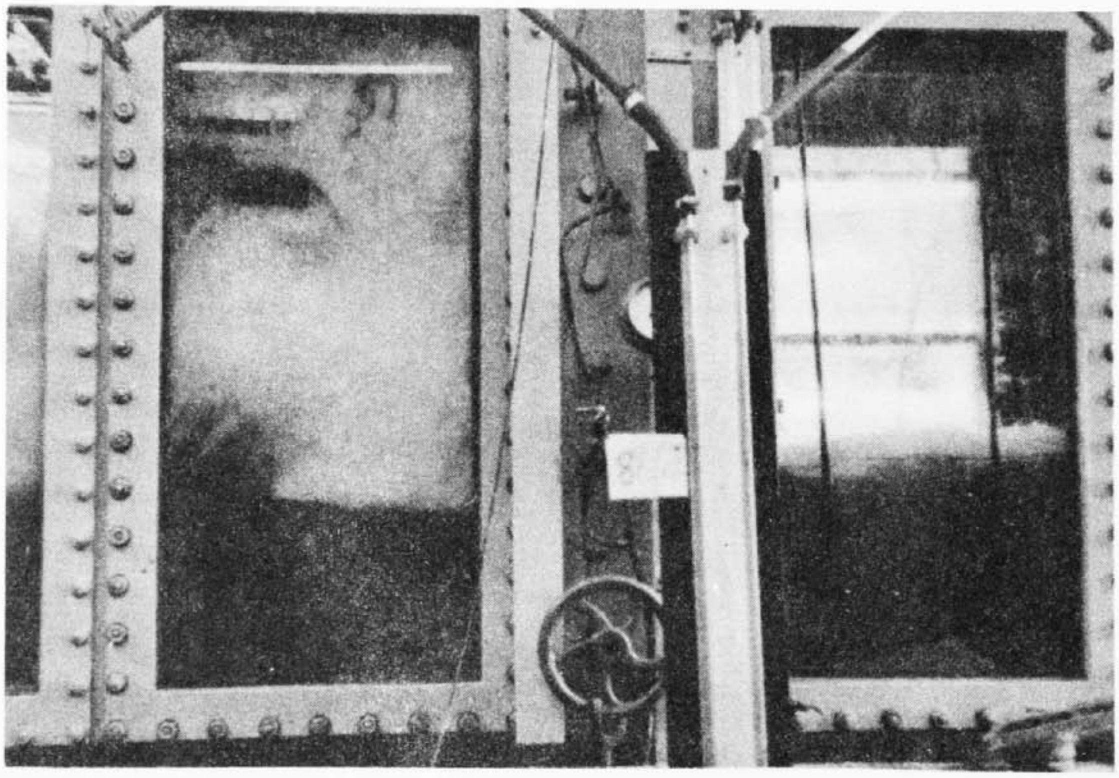
For each test, a photograph of stage 3 of the research vehicle was taken for record purposes. Several of these photographs are reproduced below to allow some comparison to be made between different test conditions in the same series.

The photographs show the front of the flash chamber in which the moving wall is fitted. The brine enters the chamber from the left, flows through the brine transfer arrangement, across the chamber and under the moveable wall. Further flash-off can take place on the right hand side of this wall if the stage is less than 100% efficient.

For photographs Fig. A4.3 - Fig. A4.10, the chamber efficiency is approximately 99%.



<u>Fig. A4. 1</u> The moveable wall is shown near the left side of the right hand window. The 1st part of the chamber is long and complete flash-off takes place. The brine circulation is 350, 000 lbs/hr. ft. but all other parameters are at the standard conditions (Section 6. 1). The effective length of part A of the chamber is 47".



<u>Fig. A4. 2</u> Similar conditions to Fig. A4. 1 but the wall has been moved upstream and the efficiency has dropped to 96%. It can be seen that some flash-off is taking place on the downstream wall.

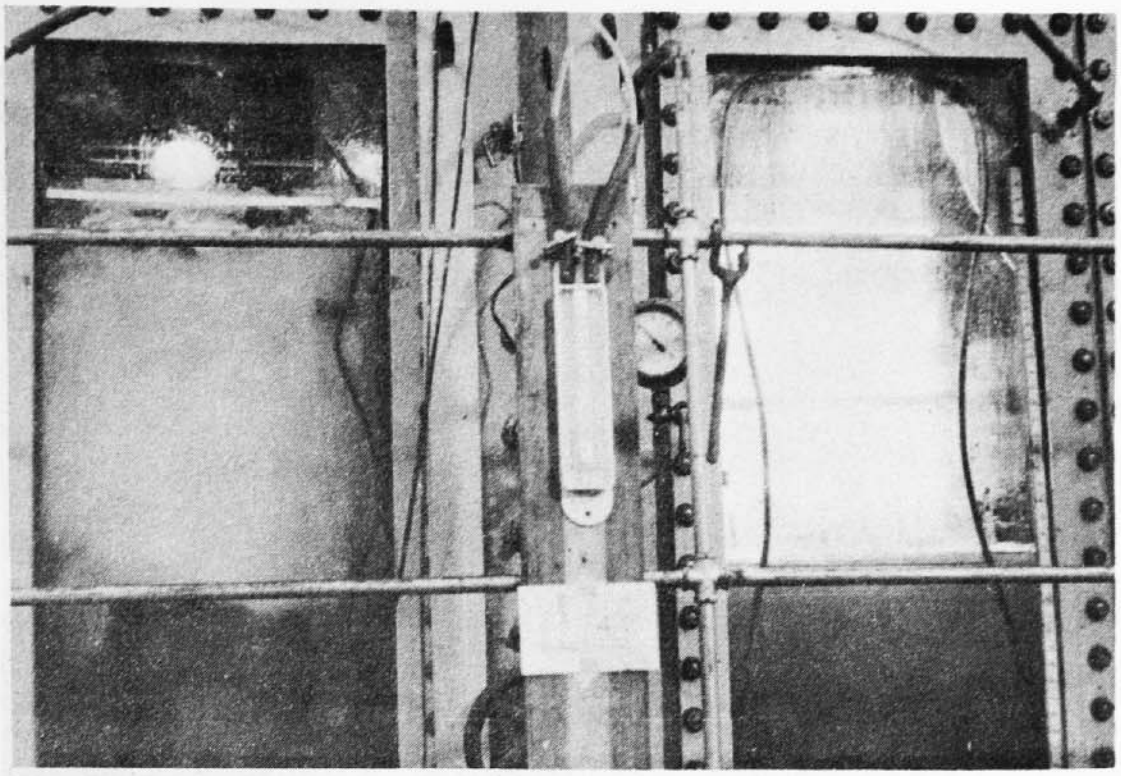


Fig. A4. 3 The brine circulation is reduced to 200, 000 lbs/hr. ft. with the wall at 23. 5" and at the standard test conditions.

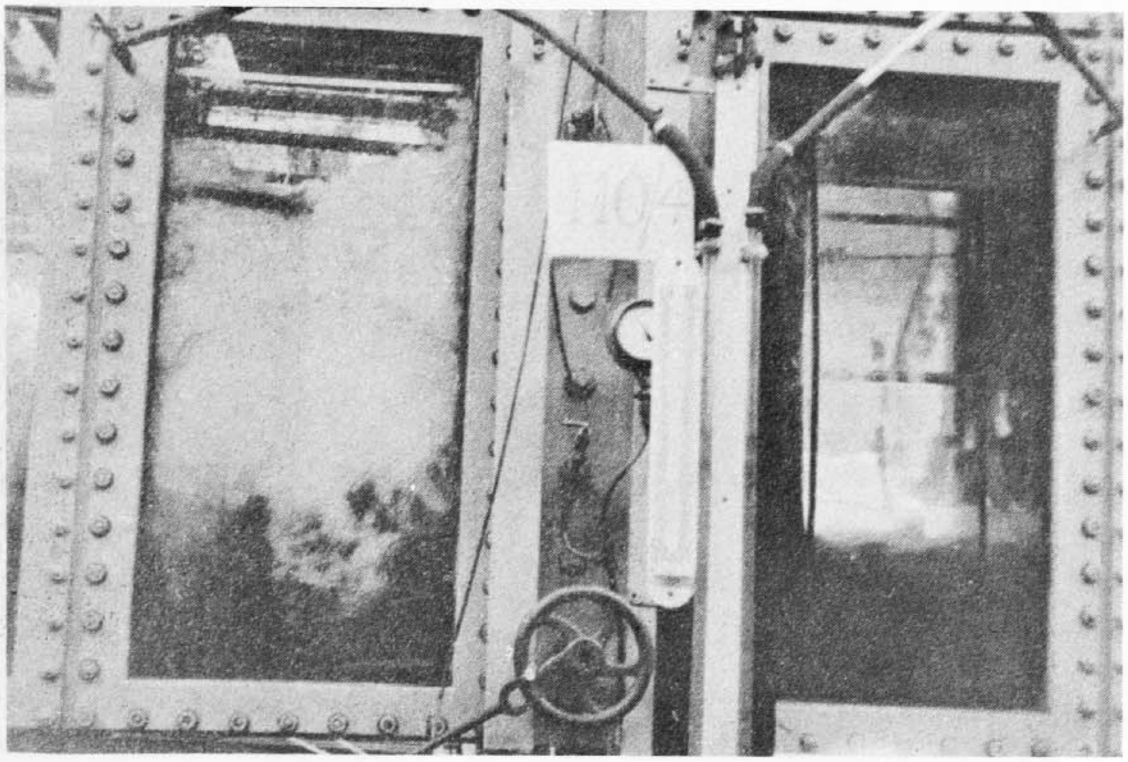


Fig. A4. 4 The maximum brine circulation of 500, 000 lbs/hr. ft. is at the standard conditions except that the temperature and the baffle plate distance from the 1st orifice have been increased. (Section 6. 3).

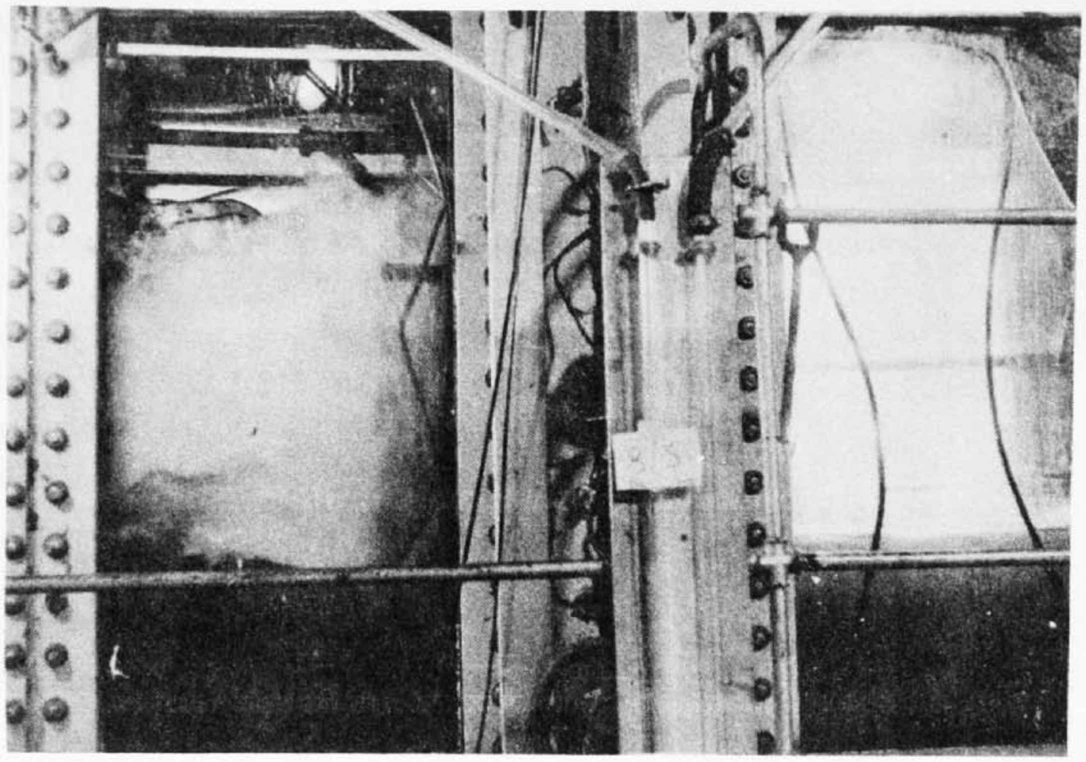


Fig. A4.5 Low flash-off due to 1.8°F temp. drop per stage. Standard conditions and brine circulation at 250,000 lbs/hr. ft.

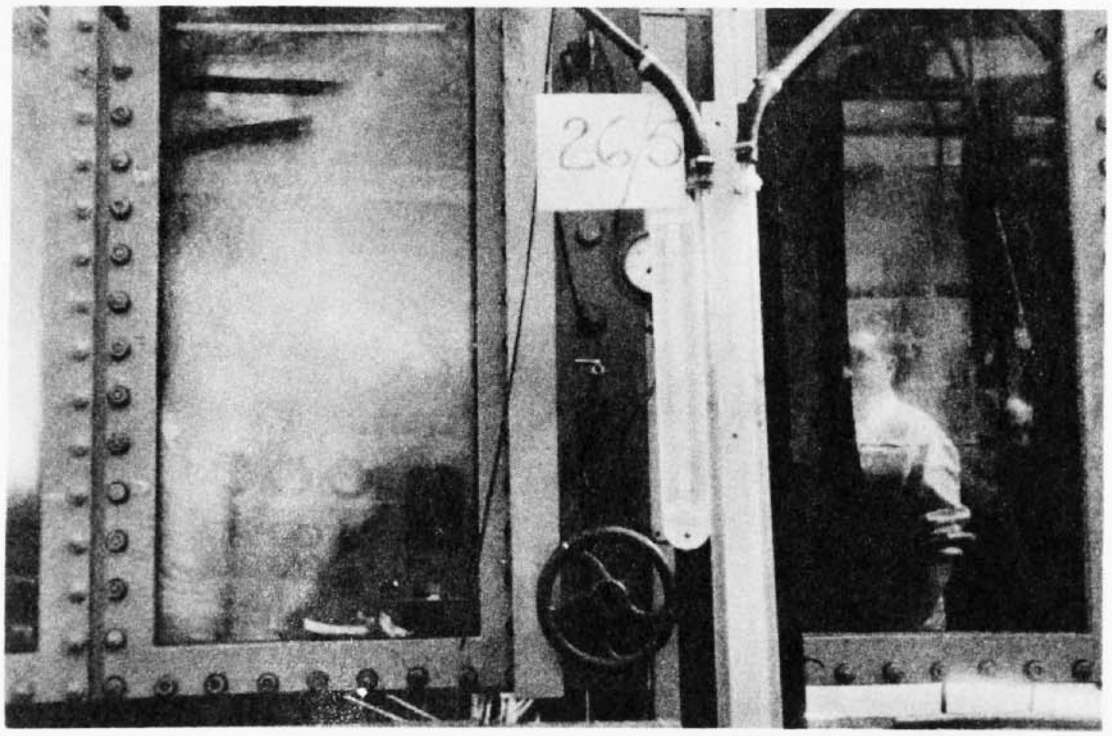


Fig. A4.6 High flash-off due to 8°F temp. drop per stage. Other conditions as for Fig. A4.5.

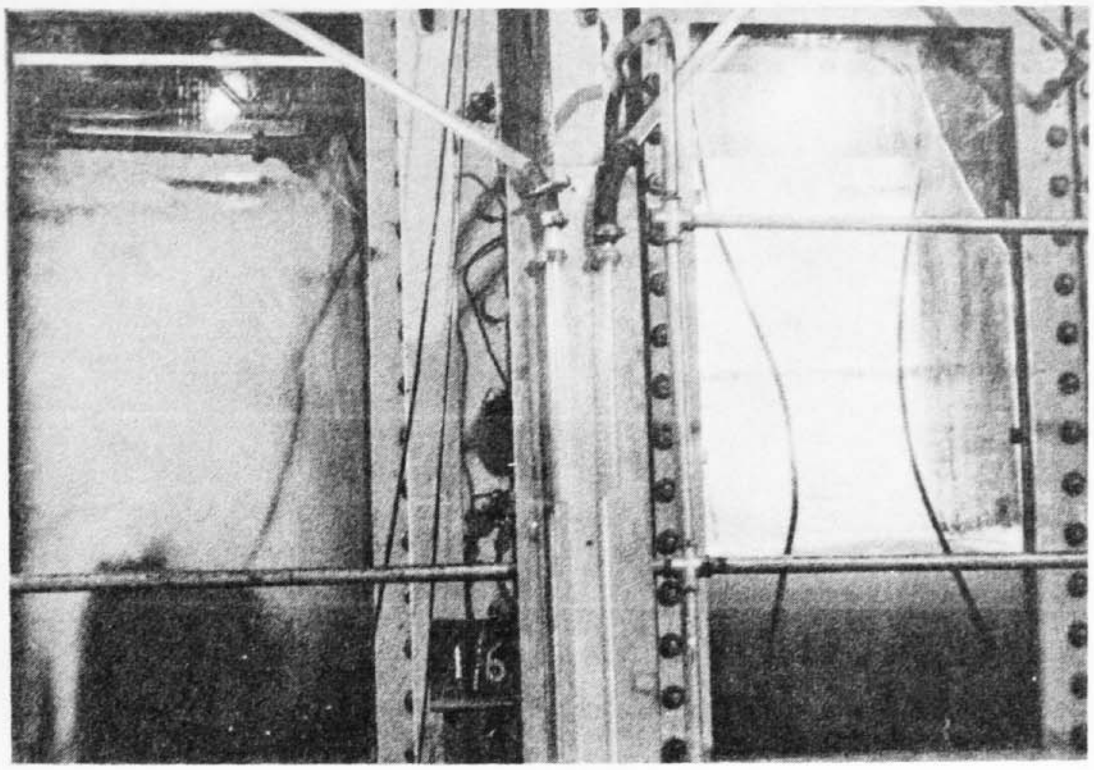


Fig. A4. 7 Standard conditions at 200°F. The brine circulation is 300,000 lbs/hr. ft.

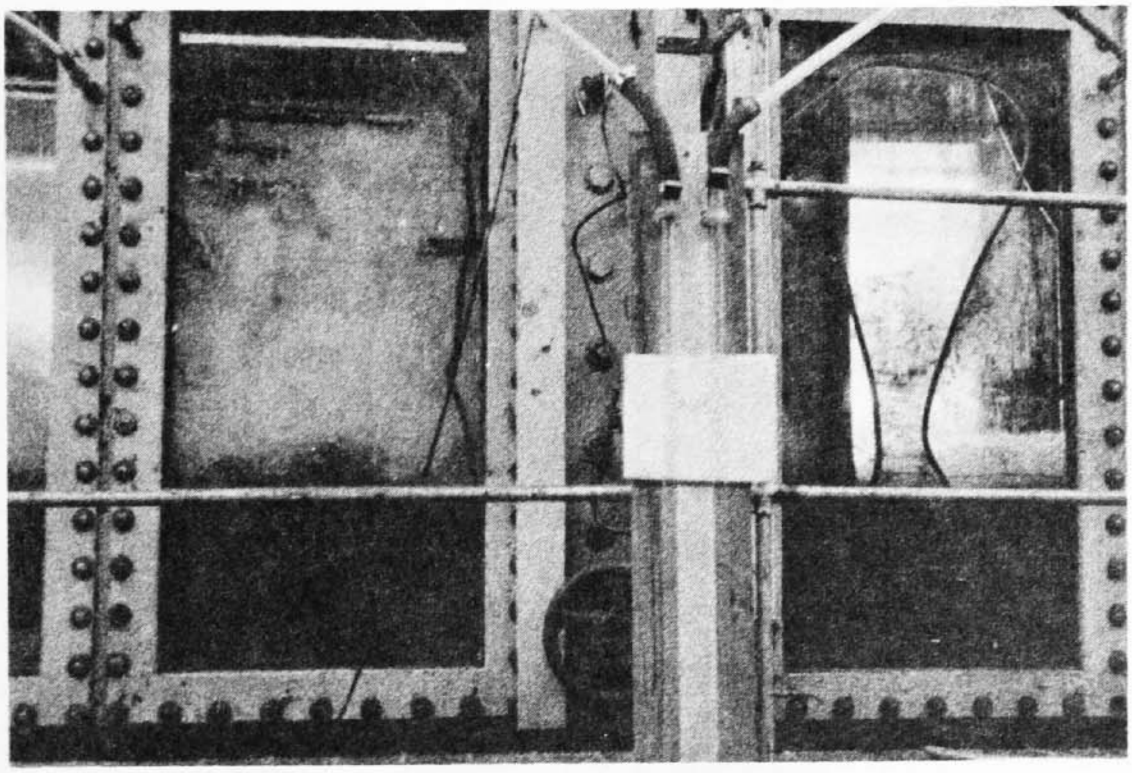


Fig. A4. 8 Low temperature test at 100°F. The brine circulation is 250,000 lbs/hr. ft. Other conditions as standard except for the baffle plate which is 6" high and 12" from the plane of the first orifice.

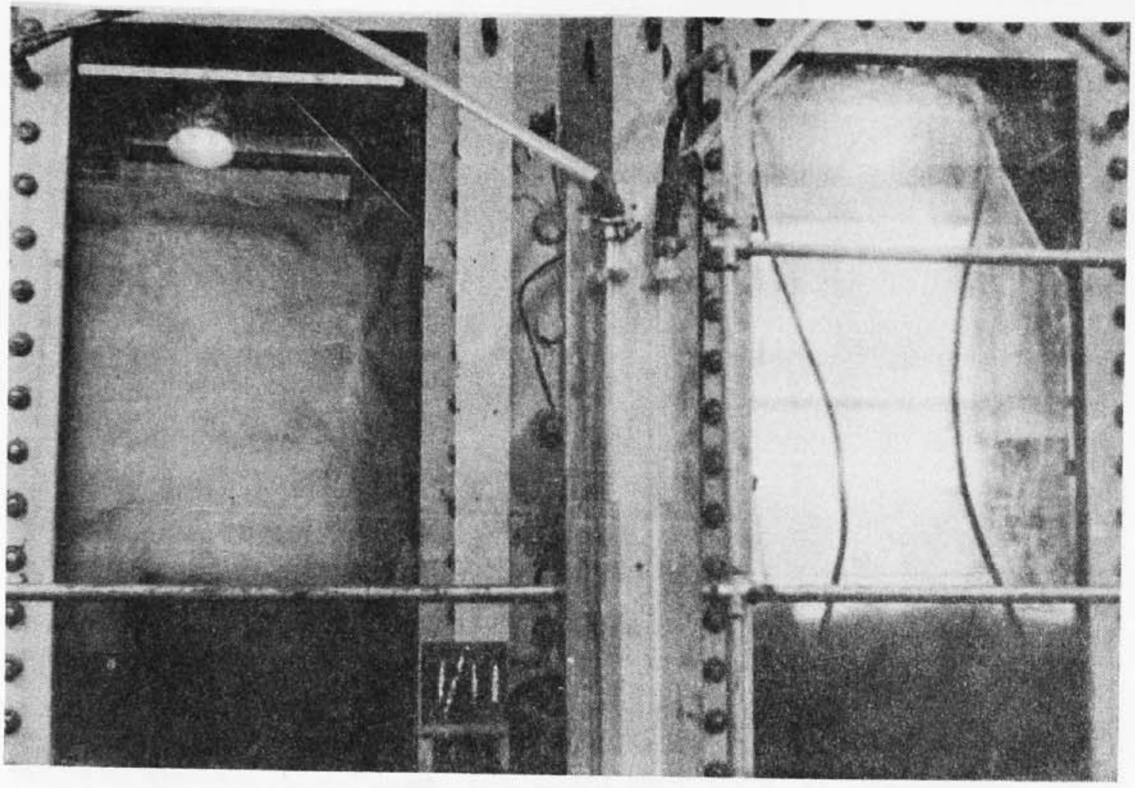


Fig. A4.9 15" long splash plate fitted in place of the standard 10" plate. The brine circulation is 300,000 lbs/hr. ft. The brine-foam mixture is deflected away from the vapour-brine separator, but a longer chamber length is required for equilibration of the flashing brine.

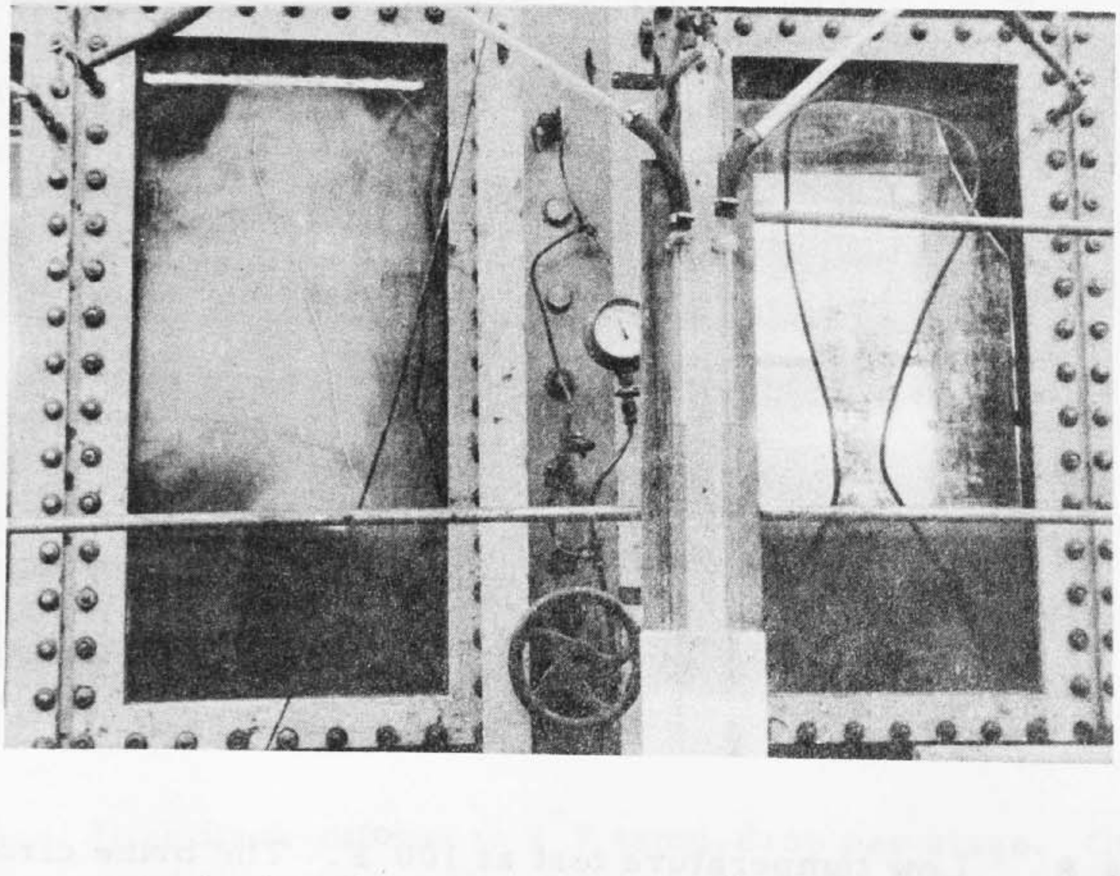


Fig. A4.10 Splash plate length reduced to 5". Conditions as in Fig. A4.9. The brine-foam mixture tends to be thrown into the separator.

APPENDIX 5

REFERENCES

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