LOW PRESSURE EVAPORATORS.*

SUBMERGED COIL TYPE.

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It is the general policy of the Navy Department to equip all naval vessels with low pressure evaporating plants. New vessels are having such plants furnished as the original installation, and vessels to remain in commission are having their old plants converted as fast as funds and opportunity permit.

Low pressure evaporation is supplanting high pressure in our service for several reasons. The first and most important one is that it permits the use of exhaust steam which on most naval vessels is available without cost, and consequently the fuel consumption of the vessel is reduced.

A second reason is, that a low pressure plant (if properly designed and operated) will scale only to a slight degree in operation and as a result there will be no falling off in water production nor will the frequent scaling of tubes be required. The temperature corresponding to 10 pounds gauge is, with saturated steam, 240 degrees F. It has been found that hard scale, a sulphate deposit, ceases to form at 265 degrees F. From this temperature down to about 195 degrees F, a softer carbonate scale only, is formed. Consequently, if wet steam only, at a pressure not exceeding 10 pounds is used, sulphate scale is not formed. If the pressure is kept under 5 pounds, and proper submergence of tubes is obtained, scaling will be

* This article is based on the author's experience as Planning and Drafting Superintendent at the Navy Yard, Boston, Mass., in the design, installation, and operation of low pressure evaporators on the U. S. S. *Brazos*, *Denver*, *Utah*, and *Florida;* on personal observation of the operation of such plants on the U. S. S. *Raleigh*, *Wyoming*, and *Colorado;* and on reports of the operating experiences of the personnel on other vessels of the Navy having low pressure evaporator plants.

practically eliminated. If, however, live steam reduced through an orifice or a reducer is used, the steam will superheat and scale will result as in high pressure evaporators, unless special means are provided for abstracting the superheat before admitting the steam to the evaporators.

A third reason is that, by using a high vacuum, a large temperature range is obtained permitting operation in multiple effect, either double, triple, or quadruple, with consequent increase in economy. Multiplication of effects, however, does not correspondingly increase capacity.

At present the low pressure evaporation principle is being applied in two distinct and different manners on naval vessels. Low pressure advantages are inherent in low pressure and corresponding low temperature, and may be obtained by either method. One application involves the recirculation of the water in the evaporators in the form of rain over the tube nest, the water level in the evaporator being kept theoretically below the bottom row of tubes. This system, the film or flash type, is described at length in the Journal of the American Society of Naval Engineers for May, 1923. This is the type installed at present on all new vessels of the Navy, being the first naval application of low pressure evaporators on a large scale.

In the other application, the tube nests in the evaporators are submerged about as formerly in the old high pressure evaporators, and no special circulation system is required. The simplicity of this system marks it as the next step in the development of low pressure plants and makes it the best method for realizing the benefits of low pressure evaporation on Naval vessels. Several applications of this design have been made at the Boston Navy Yard, with results that confirm this statement. A plant built on this system as actually installed and operated on the U. S. S. *Denver* will here be discussed and compared with Lillie type evaporators.

On the arrival of the U. S. S. *Denver* at the Navy Yard, Boston, in the fall of 1923, the Yard was directed to convert the existing double effect high pressure plant to a double effect low pressure, non-recirculating plant. On examination of the *Denver's* existing equipment, it was found that both evaporator shells were seriously corroded and had been patched. It was decided not to use these evaporators again and they were removed and junked. There were on hand in the Yard two ex-*Utah* high pressure evaporators in good condition and these were selected for the *Denver*. For a distilling condenser, the existing port auxiliary condenser on the *Denver* was taken and relocated. Only one new item of equipment was supplied, this being a small reciprocating pump drawn from store for use as a brine overboard pump. A type plan of the layout is given in the sketches following. For convenience in tracing the piping, and for ease of comparison with similar sketches in the article on the Lillie type referred to above, the sketches are separated into

(1) Steam lines and first effect tube nest drain.
(2) Salt water piping.
(3) Vapor and fresh water piping.
(4) Air removal connections.

Steam for the plant is obtained from a 3½ inch connection to the auxiliary exhaust line. No connection to a live steam line is furnished in the evaporator room, this being to prevent the crew by any possibility wiredrawing the steam to a low pressure and consequently sending superheated low pressure steam to the first effect. The evil effects of using superheated steam, giving a temperature above 240 degrees F., have been noted above. On vessels of the class described here, sufficient exhaust steam is always available to operate the plant. On other vessels, if more steam is required, it may be obtained by bleeding live steam into the exhaust steam line as far away from the evaporators as possible, thus giving the steam a chance to lose its superheat before it arrives at the first effect coil.

A compound gauge and a 300 degree thermometer are installed on the line to the first effect in order that a check on the feed steam may be kept. The thermometer is considered more important than the gauge, especially for ships using live steam through a reducer.

A section of the tube nest is given in Figure 5. The steam passes through the tubes in the same manner as in the old high pressure operation. As the steam goes through the various passes, it is condensed and the condensate is taken out through a drain pipe at the bottom of the front head. A trap is fitted to maintain the water level just below the bottom row of tubes and thus prevent steam from blowing through.

This condensate, not being new water made, is returned for boiler use again, either to the hotwell, the auxiliary condenser, or the main condenser as shown in Figure 1. It is not fit for ship use owing to the presence of boiler compound or oil. The condensate comes out at a temperature nearly corresponding to the entering pressure, and its heat is partly made use of to heat the salt feed water. The heater used is of the same design and size as is used on the plants installed on the *Florida* and *Colorado*, with about nine square feet of surface, but this appears to be insufficient really to cool the condensate or to warm up the feed to any great extent. This heater with its by-pass is mounted below the drain regulator.

Two relief valves, one set at 12 pounds and one set at 15 pounds are fitted as shown to protect the coil. It may be noted that in this installation, as the coil was originally designed for high pressure operation, the protection is unnecessary as a safety device but is still required to prevent violent (though improbable) changes of temperature in the first effect coil due to high pressure.

Figure 2 shows the salt water piping. Circulating water is taken from the same sea chest which formerly supplied the port auxiliary condenser in its old location. A check valve is fitted just inside the stop valve. The circulating unit is part of the combined air, circulating pump, and condenser, formerly

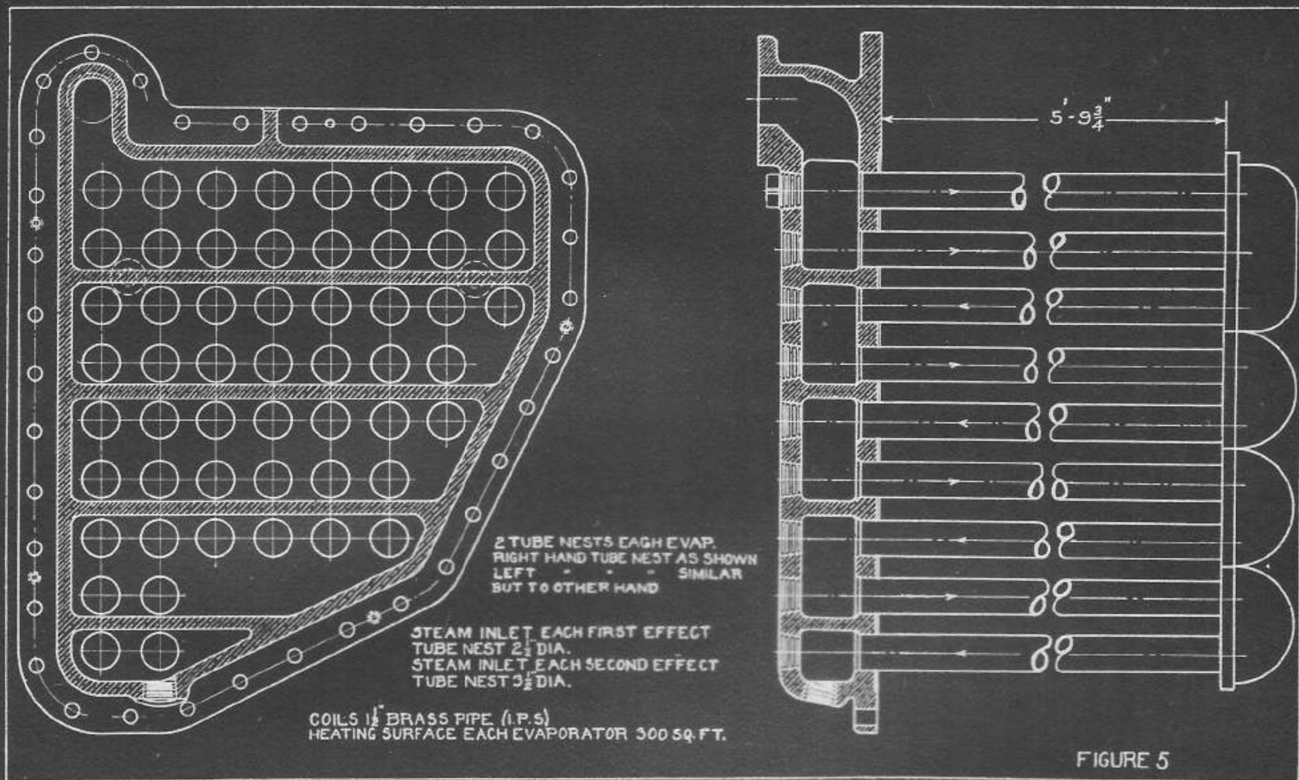
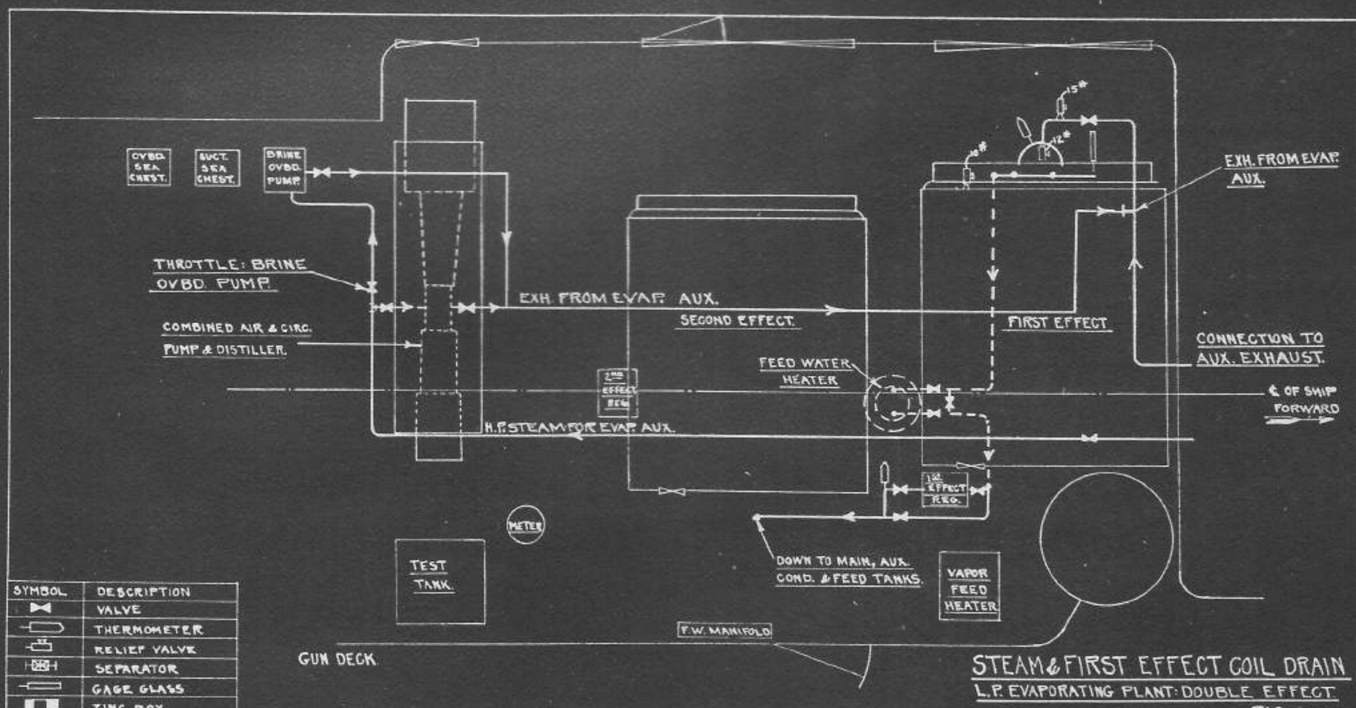


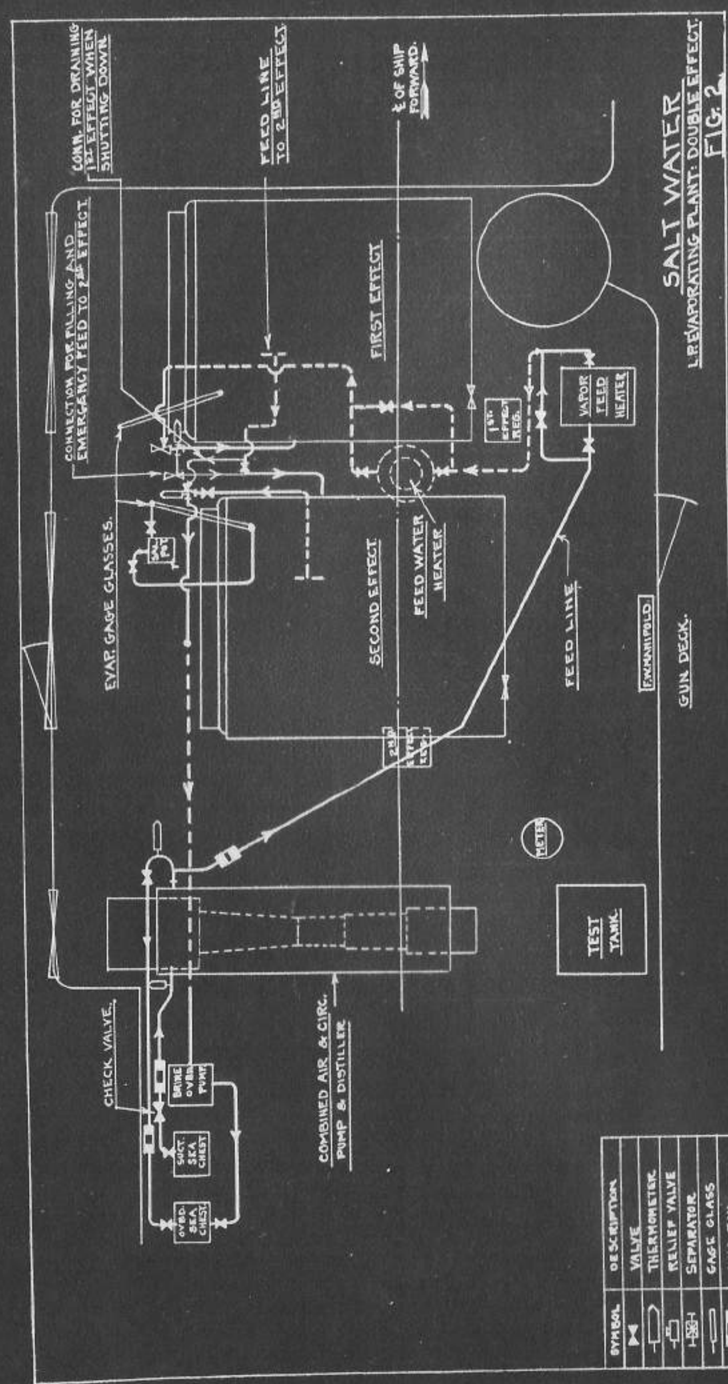
FIGURE 5



STEAM & FIRST EFFECT COIL DRAIN

L.P. EVAPORATING PLANT: DOUBLE EFFECT.

FIG. 1.



SALT WATER
L.P. EVAPORATING PLANT: DOUBLE EFFECT.
FIG. 2.

the port auxiliary condenser of the *Denver* and now located in the same room as the evaporators and on the same level. This unit is 6 inches × 7 inches × 10 inches × 10 inches. The circulating water passes through the condenser and goes overboard through the old port auxiliary condenser discharge sea chest. A gate valve is fitted in the discharge line just beyond the condenser discharge for the purpose of throttling the discharge and keeping its temperature as high as is consistent with the vacuum desired. The feed line to evaporators is taken off just inside this throttle valve as the throttling keeps up a slight pressure which helps to feed the evaporators. A thermometer is provided here to check the discharge temperature. The feed water leaving the condenser circulating discharge is at a pressure varying from 0 up to 5 or 10 pounds depending on the amount of throttling and the pump speed.

The feed water is first led through a "U" tube Dyson vapor heater placed in the vapor line between the first and the second effects. This heater was originally designed for the high pressure evaporator plant on the *Raleigh* but sent as excess material to Boston when the *Raleigh's* designs were changed. It has 30 square feet of heating surface with a 5-inch vapor inlet and outlet. This heater is not altogether suitable for the work it is now doing. The area through the tubes is insufficient to provide a free passage for the vapor and consequently a difference of vacuum of about 5 inches due to this throttling effect always exists between the two sides of the heater. As the best thing available without cost (an important consideration on the *Denver* job), the heater was nevertheless installed. It is located on a bulkhead in the evaporating room just under the deck. A by-pass is fitted in the salt feed line to cut out the heater in case of a leak from the salt water (pressure) side to the vapor (vacuum) side. A thermometer was temporarily installed for the test period on the outlet side to obtain the rise of temperature of the feed water in the heater.

After leaving the vapor heater the feed passes down through the deck to the coil drain heater located just below. A by-pass is provided for the feed here as is the case of the vapor feed heater. After leaving the coil drain heater, the feed rises through the deck to the front of the first effect evaporator shell. Here a permanent thermometer is provided to show the final temperature of the feed as it enters the shell after passing through the two heaters.

All the feed enters the first effect shell through a hand controlled feed valve. No automatic feed regulator is provided nor has it been found desirable. The water is fed into the first shell until the level is nearly up to the top of the tube nest, thus practically submerging it. This is radically different from the Lillie type, where it is desired to keep the tubes entirely out of water. It is also somewhat different from high pressure practice, where to prevent excessive priming and salting of fresh water, the level is carried about halfway up the tube nest. This point will be more fully discussed later.

From the bottom of the first effect shell (formerly the bottom blow connection), the feed line to the second effect shell is taken off. This line has a gate valve in it to control the feed to No. 2, which is also the brine discharge from No. 1. A by-pass with a valve also connects this No. 2 feed line with the main feed to No. 1, but this connection is ordinarily closed except for the initial filling of the evaporators. It is seldom used in operation.

The water level in the second effect shell is kept up to the level of the top row of tubes, thus completely submerging them. This level is about 3 inches higher than in No. 1 effect and is also considerably higher than in high pressure practice.

From the bottom of the second effect shell (the former bottom blow connection) a brine discharge line is taken off which leads down to the brine overboard pump located below in the port engine room. This unit, a 3½ inches × 4¾ inches × 4 inches vertical reciprocating pump, draws the concentrated brine out of the second effect shell against the vacuum existing there and discharges it overboard. A salinometer pot is fitted to the second effect shell to test the brine concentration. The

brine overboard pump is run at such speed as to keep the concentration at the point desired, about 2.5/32. For ease in control, the steam line to the brine overboard pump is led through the evaporator room where a throttle valve is installed to permit regulation of the pump speed without leaving the evaporator room.

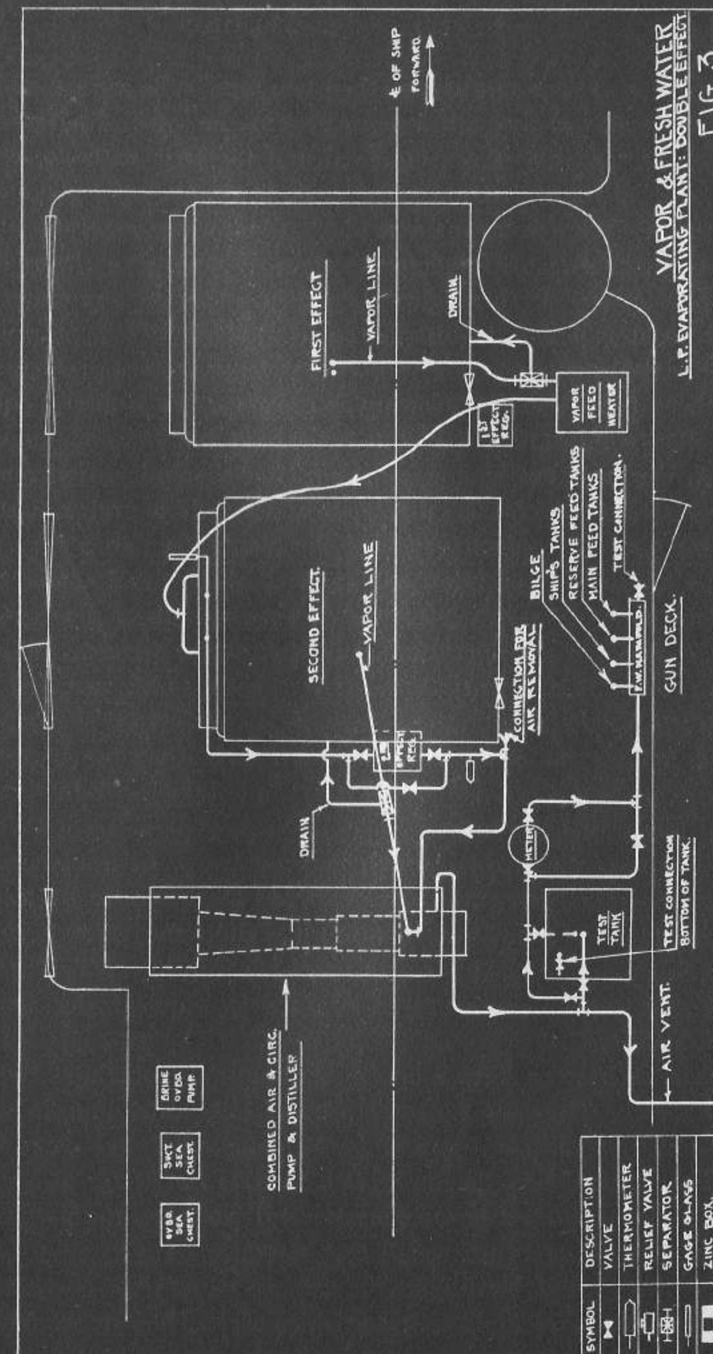
It will be noted that this is a series feed system. All feed is sent into the first effect, where part is evaporated. The remaining salt water at a somewhat higher brine concentration, is fed into the second shell where further evaporation takes place. The balance of the salt feed is all discharged from the second effect shell, thus leaving at the lowest possible temperature. No circulation pumps or intermediate feed pumps are used in this plant. The vacuum in the first shell is sufficient to pull its feed into it without a feed pump. The first shell is under a pressure 5 pounds higher than the second shell. Consequently, if a pipe of sufficient size, about 2 inches, is provided, the feed will flow from No. 1 to No. 2 shell by opening the valve in the line. This intermediate line on the *Denver* was only 1½ inches in diameter. As a result, at high capacity (over 3 pounds steam), it was not large enough to pass sufficient feed for No. 2 and auxiliary feed from the line to No. 1 shell was necessary.

Previous experience with both Lillie and submerged type coils had shown that the tubes or parts of tubes constantly washed or submerged, scaled only slowly. Lillie tubes only occasionally touched by water, scaled rapidly, and submerged tubes so high out of water as not to be constantly splashed, also gathered a coat of salt. In the submerged coil, therefore, a high water level is desirable to prevent scaling as well as to make use of all heating surface. However, here as in any boiler, a change in pressure conditions will cause priming, especially if the pressure in the shell falls or the pressure in the coil rises. To prevent solid masses of water from being thrown up into the vapor outlet pipe by priming or by rolling of the ship, a baffle plate of special design is installed in the upper half of the shell. The baffle permits vapor and some entrained spray to pass out into the vapor pipe in the top of the shell. A water level covering the tubes was desirable also for evaporative efficiency in high pressure plants, but was not attempted in practice because of the priming and salting up of the distillate which resulted. It is believed that the *Denver* installation is the first in which this high level is successfully used. The operation of the baffle plate and the condition inside the evaporator as regards priming, can be observed through a 6-inch sight port located in the back head of the shell, just above the baffle plate.

Figure 3 shows the vapor and fresh water piping systems.

The vapor made in the first effect passes through a separator located in the vapor line leading from the top of the shell. From the separator, the vapor passes through the Dyson heater previously mentioned (ex-*Raleigh*), where part of it is condensed in heating the feed. The remaining vapor passes into the second effect coil, to which the vapor condensed in the heater also drains. Here the remaining vapor condenses in the passes of the tube nest, giving up all its latent heat and some of its sensible heat. The condensate, now comprising all the vapor generated in the first effect shell, drains out the bottom of the second effect coils to a trap so adjusted as to maintain a water seal just below the bottom row of tubes. From the trap, the condensate is drawn by vacuum directly into the top of the condenser where the condensate is cooled off and drawn out by the air pump. No flash chamber is used. This method is possible as the condenser top is only about five feet higher than the bottom of the tube nest. Its advantage is that it obviates discharging hot water directly into the air pump suction with consequent liability to loss of vacuum, a trouble reported by numerous ships having flash chambers and condensate discharges from the flash chambers to the air pump suctions.

The latent heat given up in the second effect coil by the vapor from the first shell evaporates water in the second shell.



VAPOR & FRESH WATER
L.P. EVAPORATING PLANT: DOUBLE EFFECT
FIG. 3.

This vapor passes up through the same type baffle as in the first effect shell and through a separator in the vapor line to the condenser. Here it is condensed and together with the condensate from the second effect coil, is drawn off by the air pump as the fresh water made. This water may be sent through a test tank for determination of salinity or through a tank by-pass. It then flows through a meter by gravity to a manifold where it is distributed as desired.

Special attention was given on the *Denver* to the problem of making pure water at maximum capacity. A similar double effect plant installed a month before on the *Brazos*, showed high capacity, 900 gallons an hour, but a salinity of about a grain. To reduce the salinity to under half a grain on that vessel, it was necessary to hold the plant down to a capacity of 600 gallons per hour and carry a water level under the fourth row of tubes. After the departure of the *Brazos*, tests were made on the separators building for the *Denver*. These separators were identical in design with those installed at various Navy Yards on the *Florida, Utah, Arkansas, Wyoming*, and *Brazos*, and were similar in principle to those used on the *Maryland, Colorado*, and *Texas*, and other battleships having low pressure plants.

The test consisted of simulating conditions of heavy priming by sending into the separator a half inch stream of water under a low pressure and shooting into the water a jet of compressed air at 90 pounds from an open air line. This gave roughly the same velocity as attained by vapor under actual conditions.

The separators were found to be practically worthless under this test. The water came through in sheets, and it was obvious that salt spray would do the same in service. A rough computation shows that in a plant turning out water at a rate of 10,000 gallons a day per evaporator, if brine at concentration of 2/32 passes through the separator at a rate of four drops per second, it will give the water a salinity of four grains per gallon and make it unfit for boiler use. This small amount

of water passing through is nothing to a steam separator, but is fatal to results in an evaporator plant. This separator experiment showed the need of great improvement if the distillate was not to be salted up by priming.

The *Denver* separators were accordingly modified and tested again in the same manner. The modified separators proved highly effective in separating out all water and these modified separators were installed on the vessel. In operating the evaporators, the water made was carefully watched, especially when priming occurred in the evaporators due to fluctuating pressures, but the salinity was always low and varied little. The *Denver* plant consistently turned out water that tested better than the Boston city water, considered exceptionally good, and the *Denver* water was considerably better than the water made by any other low pressure plant before operated at Boston. The average salinity was under .3 over a test period of four days, and has in service since averaged .28 grain. Contrary to previous experience with both high pressure and Lillie type evaporators, this purity of the distillate is maintained at maximum capacity and consequently no slowing of the evaporators is required to make water suitable for boiler feed.

Figure 4 shows the lines for removal of air from the evaporator coils. A half inch line is led off from each coil head. The line from No. 1 head leads through a valve to a similar line from No. 2 head also provided with a valve. The two lines join and run into a larger pipe to the top of the condenser.

The importance of these air removal lines cannot be overestimated. It will be observed that all tube nests are sealed off by traps and consequently are dead ends so far as air is concerned. If no means of air removal were provided, the coils would gradually fill with air from slight leaks into the system and with air brought in dissolved in the salt water feed. Such a condition is fatal to heat transfer and the production of water will practically cease. A striking exemplification of this

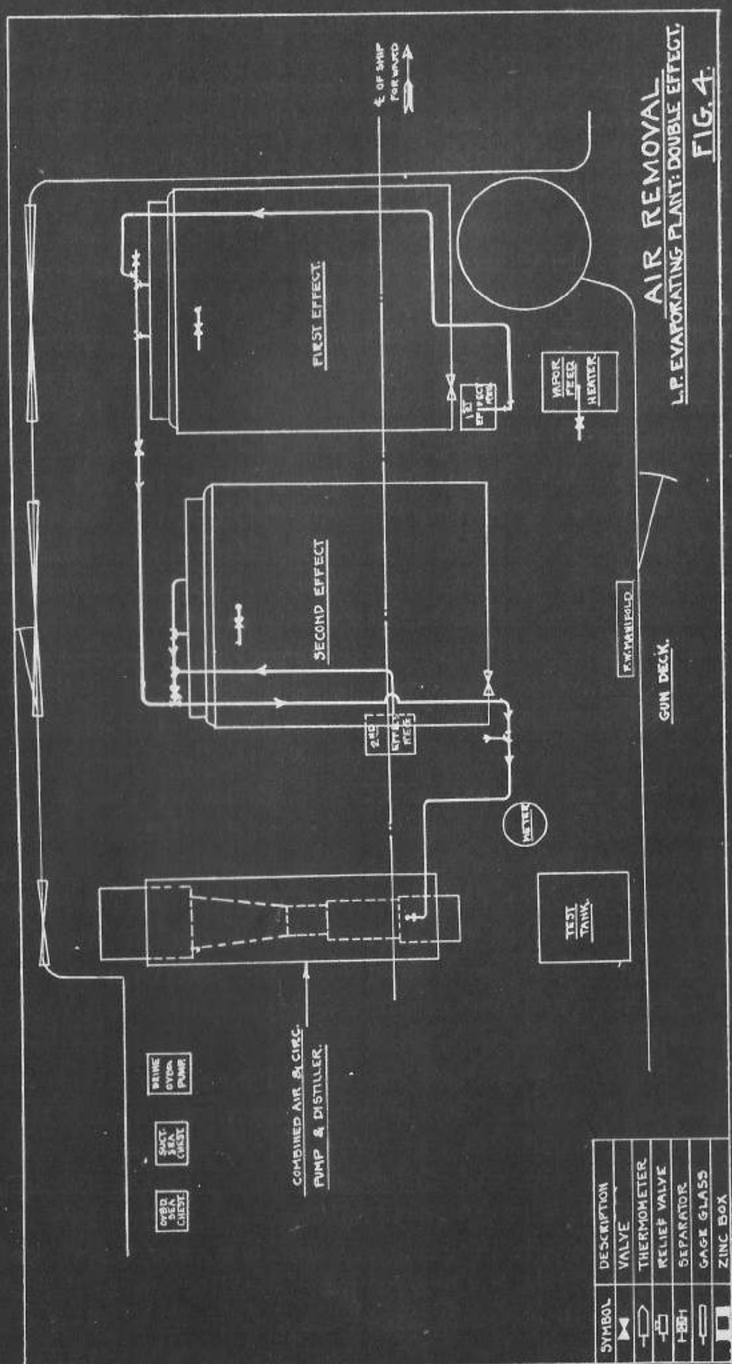


FIG. 4.

DENVER
LOG SHEET
1:00 A.M.

res - Deg			
r .	Feed	of to m	Hour
	123		11 am
	150		Noon
	150		1:30 pm
	175		2:30
			3
	154		4
	149		5
	148		6
	150		7
	162		8
	180		9
	178		10
	152		11
	164		Mid.
	148		1am
	162		2
	160		3
	160		4
	162		5
	144		6
	162		7
	150		8
	168		9
	149		10
	160		11

r hour, o

fact was given on the first test of the Lillie quadruple plant installed on the *Utah.* Owing to an error in reading plans all air removal lines were blanked in the flanged joint next to the head by the mechanics who installed the plant; but from all outside appearances everything seemed correct. The plant was started up but in spite of the fact that the steam, the circulation, and the pressures were all normal, only a total of 800 gallons of water was made as the result of seven hours of operation;—hardly more than 100 gallons an hour. The error was discovered the next day, the blanks removed, and the plant immediately started to turn out water at a 1600 gallon an hour rate.

In operation, both air elimination valves are opened wide on starting up. After the plant has settled down, the first effect air valve is left slightly cracked and the second effect valve open about two turns.

As there are no evaporator circulating pumps in the *Denver* system, no gland sealing line is provided.

The evaporator plant on the *Denver*, when completely assembled, was filled with water and all lines subjected to a 10 pound pressure. About one working day was required to make up the leaks found. This test is considered important as, in operation, the greater part of the system is under vacuum and consequently leaks do not show up. The leakage of any amount of air into the system will adversely affect results.

The day after the pressure test, steam was turned on the plant and the pumps operated for purposes of adjustment. One day was spent in getting proper steam pump operating, the steam valve gear on the old condenser combined air and circulating pump requiring considerable adjustment before evenness of operation was secured.

The day following, Friday, February 1, 1924, the plant was operated as a whole for the first time. By 11 a. m., operation was fairly steady, and a 24 hour run was begun. The log sheet for this day is given on accompanying folder. The only difficulty encountered on trial was in getting sufficient exhaust steam. It will be noted that a vacuum existed in the first coil for several hours. The ship being tied to the dock, at first had very few auxiliaries in operation. By afternoon more auxiliaries were started and a low back pressure built up in the auxiliary exhaust line. No auxiliary condenser was run during this test, all the exhaust steam going to the first effect evaporator. The pressure fluctuated continuously after the first two hours, the pressures put down being the maxima for each hour. The average pressure throughout the 24 hours was about 3 pounds. This unevenness of pressure at times caused violent priming in No. 1 shell, but had little affect on No. 2 shell.

The total production of water for the 24 hours was 22,880 gallons, giving an hourly average of 953 gallons, with an average salinity of .284 grain per gallon.

The best hour produced 1,100 gallons of .4 grain water with a maximum steam pressure of 4 pounds and a brine discharge concentration of 2.5/32. The worst hour was the first, which produced 650 gallons of .3 grain water with the steam under a 5 inch vacuum and a brine concentration of 3.25/32.

The following Monday, February 4, operation was resumed and maintained continuously for three days. The ship's regular evaporator room force took charge of operation. For their first 24 hours of operation they turned out 23,000 gallons of water, having an average salinity of .3, using exhaust steam under an average pressure of 2 pounds at the first effect coil, the maximum pressure for that day being 4 pounds, and the minimum 0 pound. The brine discharge concentration averaged about 3/32, running up occasionally to 3.5/32.

At 2 a. m., Wednesday, February 6, the plant was shut down, having run for 62 hours. In this time it produced 58,990 gallons of water on an hourly average of 952 gallons. The production when the plant stopped showed no signs of falling off due to scaling or other causes.

It was desired, previous to the departure of the vessel, to draw a coil from each shell for examination as to scaling. As

much running as possible was, of course, desirable to afford ample opportunity for scale to form but as the vessel's sailing date was set for February 7, the examination could not be delayed beyond February 6. On that day, then, the plant was shut down in the early morning for examination and the right hand coil in each evaporator drawn out of its shell.

As had been anticipated, no scale had formed on any tube nest. The coils, which were the ex-*Utah* high pressure coils had been scaled by Yard workmen but it was not possible to get at all the old hard scale adhering to the tubes when scaling these coils for use on the *Denver*. The tube nests had been put in the shells with this scale remaining. A considerable quantity of this old scale was now found to have cracked off and lay in the bottom of each shell. No new scale of any kind had formed.

It was realized that a period of operation of 62 hours was not a long enough time to form an opinion as to the amount of time it might take to scale up, but as no scale began to form after 62 hours, it seemed unlikely that scaling to any extent was likely after longer service. The *Denver* has since reported that after seven weeks of operation at an average capacity of over 20,000 gallons, a 1/16 inch coat of scale was found on the tubes of No. 1 coil; the tubes of No. 2 coil were found clean. This accords with theory, as the temperature in No. 1 coil is about 220 degrees F., which is higher than the critical point for formation of carbonate scale.

A study will now be undertaken of the efficiency of this plant. A temporary meter was installed to measure the feed steam used. This meter was calibrated in place.

For the four-hour period from 9 p. m. to 1 a. m., the average conditions as shown by the log are:

Water, gallons	977
Steam used, gallons	597
Brine concentration	3.5
Steam pressure, pounds	3

No. 1 shell, inches	9
No. 2 coil, inches	15
No. 2 shell, inches	24
Vacuum, inches	26
Over discharge, degrees F.	80
Heater discharge, degrees F.	160
Feed temperature, degrees F.	166

Using the steam pressure above, the same brine concentration at discharge and the same heating effects of the heaters, the theoretical performance of the plant follows:

Assuming 1.69 pounds of water per pound of steam used, there will be discharged .677 pound overboard at concentration of 3.5/32. This gives a total feed of 2.367 pounds per pound of steam.

In No. 1 shell this is heated from 166 degrees to 194 degrees requiring 2.367(194-166)=2.367×28	=	66.2	B.T.U.
The pound of steam has a latent heat of		959	B.T.U.
Leaving		892.8	B.T.U.
There will be evaporated in No. 1 shell $\frac{892.8}{978}$	=	.914 lbs.	
Hence the feed to No. 2 will be 2.367—.914		1.453 lbs.	
In the heater 2.367 pounds are raised from 80 degrees to 160 degrees F. requiring 2.367×80	=	189.5	B.T.U.
There is condensed here $\frac{189.5}{978}$	=	.193 lbs.	
Leaving .914−.193=.721 pounds to go to No. 2			

In No. 2 shell the feed gives up 1.453×(194−141)	=	77	B.T.U.
Latent heat is .721×978	=	707	
Giving for evaporation in No. 2 shell		784	B.T.U.
There is evaporated $\frac{784}{1012}$	=	.776 lbs.	
Total evaporation .914+.776	=	1.690 lbs.	

Discharged .677 pounds overboard at 3.5/32 concentration.

It appears from the above that if there were no losses, under conditions above, 1.69 pounds of water per pound of steam should be made. Actually, the plant turned out 1.64 pounds of water per pound of steam, giving it an efficiency of

$$\frac{1.64}{1.69} = 97 \text{ per cent.}$$

The low pressure plant as installed on the *Denver* is simple in operation. But two steam driven auxiliaries require to be run, and the feed valves to the evaporators require little adjustment to maintain a steady level. The complications of circulating pumps are altogether absent. No one who has ever run a Lillie plant would expect a green crew to pick up its operation in 24 hours, so that after that period they could drive it steadily themselves and get maximum production hour after hour. Four non-rated men and a chief petty officer took charge of the *Denver* plant after one day's operation by the Yard force, and thereafter without supervision exceeded even the production obtained by the Yard.

The installation, after three weeks of service operation, reached its best day's production with a daily rate of 28,000 gallons of .29 grain water at a steam pressure of four pounds. The same double effect plant on another vessel capable of supplying exhaust steam at a steady pressure of 5 pounds would undoubtedly produce an average of 25,000 gallons a day.

As the standard type for future Navy installations, the submerged type evaporating plant may be compared with the film type under five heads:

(1) Cost of installation.
(2) Cost of operation.
(3) Ease and certainty of operation.
(4) Thermal efficiency.
(5) Capacity.

For the purpose of this comparison, two installations made at the Boston Navy Yard will be used as types. The film type will be represented by a quadruple plant as installed on the *Utah;* the submerged type by a quadruple plant based on the *Denver* double effect plant. The comparison is rendered more apt as the *Denver* evaporators are the ex-*Utah* high pressure evaporators, with the same shell dimensions as the present *Utah* low pressure evaporators. These shells are all about 6 feet in diameter and 6 feet long. The *Denver* coils have a heating surface of 300 square feet per evaporator; the *Utah* film type coils have a heating surface of 400 square feet per evaporator.

The items required for each plant (duplications installed on the *Utah* not included) :—

	Lillie	Submerged
Air pump	1 }	1 combined air
Circulating pump	1 }	and circulating
Brine overboard pump	1	1
Brine circulating pumps	4	0
Total	7	2

(1)—Cost of installation.

(*a*) The submerged type evaporator is essentially a simple system and dispenses with circulating pumps, circulating pump motors, suction piping and discharge piping for the circulating system, sump tanks, sump strainers, automatic feed regulators, feed strainer baskets, distribution plates, and the special film type coils, all of which are part of the film type evaporating plant. Based on the prices paid for the pumps and coils supplied on Bureau contract for the *Utah* film type plant, and on the cost of building at the Yard and installing on the *Utah* the other accessories required, it appears that a quadruple film type plant will cost 20 per cent more than a submerged quadruple plant of the same size. In the ordinary case, this will amount to about $15,000.

(2)—Cost of operation.

(*a*) The largest difference in operating cost comes in the operation of the auxiliaries. As the submerged type plant runs without brine circulating pumps and with a minimum number of other auxiliaries, the fuel consumption chargeable to the plant is much reduced. The engineer officer of the *Utah* reports that to operate the auxiliaries required for his plant, running either as two double effects or one quadruple effect, takes three tons of coal a day, for which he gets about 30,000 gallons of water, or about 10,000 gallons of water per ton of coal. The *Denver* plant runs on about one-fifth of a ton of coal per day for auxiliaries, for which it produces over 20,000 gallons of water, or about 100,000 gallons per ton of coal.

(*b*) On the personnel side, at least two men per watch are required to tend the feed and the circulation on a quadruple Lillie plant, two evaporators being more than sufficient to keep one man engaged trying to maintain a steady water level in them. With the submerged type, the absence of circulation and the large volume of water in each shell, make water tending simple. One man can easily look after all four evaporators and their auxiliaries. With limited engineering personnel, this side of the cost of operation is of importance.

(3)—Ease and certainty of operation.

Any person who has been associated with the operation of a Lillie type plant realizes the difficulties involved in the circulation feature. Suction troubles were, and are, prominent and chronic problems. Getting a circulation is often difficult. On most ships, with the pumps located in the evaporating room with heads of three feet or less, the circulation problem will always be acute. Since in each evaporator, the water is practically at the boiling point, it is always likely to flash in the pump and spoil the suction. In addition, slight air leaks along the packing of the pump shafts produce the same result. To offset this, gland sealing and all sorts of packing combinations have been tried out but the problem is still a live one on most ships. Tight packing wears out the shaft; loose packing spoils the suction. A solution used on the *Utah* and *Florida* was to place the pumps in the engine room 20 feet below the evaporators, with great improvement in results, but this is a solution not applicable to all vessels owing to lack of space or lack of height below the evaporators. It involves also considerable expense for the long pipe leads required.

Assuming that circulation is obtained, even distribution over the spray plate is not obtainable owing to variable trim, and clogging of distribution plates and baskets. Some tubes get little or no rain. Scale forms, cracks off, and clogs feed strainers, which on the *Utah* require to be shifted and cleaned out every watch.

The water level must be closely watched. Low water in any shell causes the circulation in that shell to cease and upsets the operation of all four units. High water causes violent priming, high salinity, and practically stops evaporation in that shell, also upsetting the plant operation.

Automatic feed regulators, provided with all Lillie plants, have proved unreliable as they soon clog with scale. Their use has been discontinued on many ships, as reported on the *Maryland*. Hand feed requires close watching as the feed pressure is usually supplied by the brine circulating pumps and pressure may exist or not, depending on how well the circulating pump is operating at the moment. A given opening of the feed valve may at one time give no feed at all, and a few

minutes later flood the shell before the man on watch can catch it.

High water, low water, poor circulation in any shell, and the production of the entire plant drops very low or ceases. It takes a good crew to strike a balance again and resume normal production in less than half an hour.

Scaling tubes is not eliminated. It is inherent in the rain feature that some scale will form, owing to intermittent contact of rain with tubes. Circulation troubles aggravate this feature. The *Maryland*, operating with 5 pounds or less, reports the necessity of scaling first effect coils weekly, and then circulating dilute acid through all three effects for about eight hours. In addition, a daily shut down for an hour is required to open and clean sumps and strainers. On the *Utah*, there is a weekly shut down for cleaning sumps, strainers, and spray plates. Every other week the first effect pumps are taken apart and scaled, and the brine circulating lines are opened up at the same time.

The staggered tubes and close spacing necessary in film type coils to obtain distribution of the rain over the tubes, makes it practically impossible to scale any but the outer tubes, leaving the great mass of tubes in the inside of the coil to accumulate scale which can be removed only chemically, if at all.

For the *Denver* submerged type plant, the simplicity of its set-up insures both ease and certainty of operation. Circulation, with all its troubles, is gone. There are no brine circulating pumps to lose suction, or leak gland sealing water over the decks; no brine circulating pipes with additional chances of heat losses and air leakage; no spray plates; no feed strainer baskets to shift and clean; and no sumps to keep cleared out.

There is a large volume of water in each shell. Variations in water level cause no annoyance. The feed pressures, being the difference in pressures between shells, are practically constant and the hand feed valves may soon be set at the opening required and then need little attention. The tubes, submerged at all times, are favorably situated to resist all scaling due to mechanical deposition. The *Denver* reports that after seven weeks the second effect coils showed no scale at all, and the first effect coils showed only a coat 1/16 inch thick. As the *Denver* coils are designed for accessibility for scaling, it was a simple matter to knock this coat off. The *Denver's* experience shows that only once in six weeks is even a light scaling desirable. Consequently, the labor of frequent scaling is avoided and the capacity remains high over a long period. Shut down for circulating dilute acid or cleaning sumps is unnecessary. Only one pump, the brine overboard discharge pump, is required to work under a vacuum instead of five as in the Lillie system. This pump requires only a two-inch lead from the fourth effect evaporator. No trouble or expense will be found in locating this one pump sufficiently below the last effect shell to insure its maintaining a suction. This unit, a small reciprocating pump on the *Denver*, was placed in the engine room below the evaporators and never once lost its suction in four days of test operation. No gland sealing line or priming connection is required with it.

That the *Denver* submerged type is practically fool-proof in operation was shown when men not previously acquainted with low pressure evaporators took charge of watches after a few hours observation and ran the plant at maximum capacity without difficulty. The converse has many times been noted on Lillie plants where experienced men have had great difficulty in obtaining circulation, and in maintaining it.

(4) Thermal efficiency.

Both a Lillie plant and a submerged coil plant will have the same theoretical thermal efficiency and, if operating under the same conditions of steam and vacuum, will theoretically produce the same amount of water per pound of steam. In actual practice, the submerged coil type has a higher thermal efficiency which, though small, is appreciable and demonstrable under two heads.

(*a*) The condensed steam in either type is at first at the temperature corresponding to its pressure. In the Lillie type

this condensate in the fourth effect immediately drains out and is lost in the condenser. In the first effect it drains out and is usually lost, owing to small heating area in the drain cooler. In either first or last effect, it is of no use in the coils, as these coils are only intermittently in contact with spray.

In the submerged type, the condensate must make several passes through tubes always submerged in brine at a much lower temperature and consequently the condensate in the first and last effects parts with a considerable amount of its sensible heat before it is discharged from the tube nest. This process represents a heat gain of approximately 2 per cent for the submerged coil evaporators.

(*b*) In the Lillie type plant there is only a small amount of water in each evaporator. This water is continuously and rapidly circulated. The circulation pump and the suction and discharge piping are required to be external to the evaporator, and are located below the evaporators in relatively cool spaces. The pumps cannot be lagged. The pipe joints and the pipes themselves cannot always be lagged. The brine must, of necessity, experience a continuous heat loss in its circulation system. This loss cannot easily be measured, but it is obviously always present. This heat loss, the submerged type coils, through entire absence of circulation pumps and piping, is spared.

These two points represent a gain in thermal efficiency for the submerged coil type which may amount roughly to as much as 5 per cent, and some gain is always present in the submerged coil design.

A direct comparison of the thermal efficiency cannot be made between the *Utah* and the *Denver* as no records exist for the *Utah*. This comparison can, however, be made with the double effect Lillie plant on the *Raleigh*, tested at Boston within two weeks of the *Denver* tests.

The same meter was used in the coil drain lines from the first effects on each vessel. This meter, being used for hot water, was calibrated in place on each ship by measuring the water in drums and comparing the quantities measured with the meter. The results were as follows:

Ship	Type	Pressure	Pounds water made per pound steam used
Raleigh	Lillie double	0 pound wet steam	1.56
Raleigh	Lillie double	5 pounds wet steam	1.50
Denver	Submerged double	3 pounds wet steam	1.64

(5) Capacity.

The capacity of an evaporator under fixed conditions of temperature and pressure, is a function of—(*a*) the effective heating surface; (*b*) the relative velocity of the steam in the tubes and the water in the shell; (*c*) the condition of the tube surfaces as regards scale; (*d*) the purity of the water desired.

(*a*) The effective heating surface first depends on the area provided by the evaporator tubes. This feature is fixed by the construction of the tube nest. All of this surface is, however, not necessarily effective. In high pressure evaporators probably half of it was never submerged and consequently was not in contact with the brine. In Lillie tube nests, observations based on five different installations showed that about one-quarter of the surface was ordinarily not touched at all by the spray and that the remaining three-quarters was not constantly surrounded by a water film. It is unlikely that more than half the heating surface in a Lillie tube nest can be considered as constantly effective. In the *Denver* installation, conditions are such that the water level can be brought up to the under side of the top row, submerging all the tubes below and constantly washing the top row by the water in ebullition. Here the entire heating surface is made effective for transferring heat.

(*b*) The rate of heat transfer is dependent on the relative velocity of the water and the steam. In Lillie tube nests the steam in the tubes has but slight velocity. It enters all tubes at once from the front head. There is no flow of steam into a tube except as necessary to replace the steam condensed in that tube. Consequently the steam contributes nothing to the relative velocity. What relative velocity does exist is supplied by the spray dripping by gravity over the tubes at a velocity never exceeding 16 feet per second.

In the submerged coil tube nest, all the steam enters at the top and passes back and forth through the tubes till it all drains out at the bottom row as water. It will be observed that this keeps up a continuous flow of the steam through the tubes, at a velocity around 100 feet per second. In addition the continuous boiling of the brine keeps it in rapid circulation adding to the relative velocity difference between the two sides of the tubes.

(*c*) The rapidity of heat transfer is vitally affected by the cleanliness of the tubes as regards scale. Even a thin coat radically cuts down the transmission and consequently the capacity. In a high pressure evaporator this scale forms quickly. In a low pressure evaporator it will not form by chemical action if the temperature is below 195 degrees, but it does form by mechanical deposition if a tube is only occasionally washed with water. In Lillie evaporators irregular circulation and the spray feature always, more or less, give rise to this condition, causing formation of scale and loss of capacity. In the submerged coil design under discussion, the constant contact of low temperature water with the tube prevents the formation of scale mechanically and retards its formation chemically.

(*d*) The purity desired in the water made is an important limiting feature in most evaporators, as forcing the evaporators causes violent priming with salting of the distillate. This feature in high pressure evaporators at maximum capacity compelled a low water level or high salinity resulted. In Lillie evaporators if the circulation is accelerated the splash from the spray plate or from the sides of the nest, fills the vapor space with spray and finely divided mist resulting in high salinity. Consequently, the large freeing surface present in the Lillie tube nest is of no great benefit in getting high capacity with low salinity. So far as can be judged, it is for this feature, the large freeing surface, that the Lillie type is chiefly used. It does not appear, however, that sufficient benefit is obtained in practice to outweigh the disadvantages inherent in the circulation feature.

The *Denver* submerged coil evaporator is so designed that the special baffle plate and separator before referred to, take care of the purity of the water under all conditions. The priming of the evaporators due to external influences resulting in changes in the feed steam pressure are of no great importance. This vessel has on test and in service consistently made water at maximum capacity of a standard of purity under .3 of a grain per gallon.

Having considered certain factors governing capacity, comparative results as obtained on various ships of the Navy may be cited. A direct comparison of capacity between the whole *Utah* plant and the *Denver* plant is impossible, as one is a quadruple and the other a double effect. However, the *Utah* plant is also piped for operation in double effect. The *Utah* reports, using feed heaters, an average output of water suitable for boilers, .5 grain water, of 800 gallons an hour. The *Florida* (similar to the *Utah*) now operates her plant regularly as two double effects. Under these conditions the vessel reports an hourly rate of 950 gallons per double effect with steam at about eight pounds, and an hourly rate of 700 gallons with steam at about three pounds. On both these ships, double effect operation uses the feed steam in one evaporator head (the normal third effect evaporator) to heat the feed water in addition to the usual heater installed between the first and second effects. This procedure on these ships increases the output over that of normal double effect, but also increases the amount of exhaust steam used.

The *Maryland* reports that one triple effect Lillie plant, with feed heaters, turns out 500 gallons of one grain water

an hour at one pound pressure, and at four pounds turns out 900 gallons. After one week's operation, the capacity for the triple effect drops, due to scale, to 500 gallons at five pounds pressure, after which the tubes are scaled.

The *Colorado* has two sets of four evaporators, each set piped in quadruple effect. This vessel turns out 850 gallons an hour with each quadruple set, the water having a varying salinity of from .6 to 1.0 grain per gallon. The steam pressure used is four pounds. A higher pressure very quickly scales up the evaporators and cuts the capacity.

A more direct comparison with a double effect Lillie evaporating plant is given by the U. S. S. *Raleigh*. This vessel was delivered at Boston the day preceeding the *Denver's* departure, and the *Raleigh* test was carried out practically under the same conditions as on the *Denver*. The *Raleigh* plant, using feed heating produced 850 gallons of .4 grain water with wet steam at five pounds pressure. At zero pressure with wet steam it produced 650 gallons per hour.*

Against these results may be set the *Denver* plant. Over the test period of four days the average output was 950 gallons an hour of .3 grain water with exhaust steam at 3 pounds. The ship could not provide a back pressure sufficient to go above 3 pounds. After seven weeks away from the Yard, the *Denver* reported an average output for that period of 949 gallons an hour with steam at 3.2 pounds, and with a salinity of .29 grains, showing results in service even better than on test.

These results are tabulated on page 464 for comparison.

The following is quoted from a report to the Bureau of Engineering made by the Commanding Officer of the *Denver* three months after the installation:—

"Since the new distilling plant has been in operation, a sufficient supply of fresh water has been obtained with practically

*NOTE: It was noted on this *Raleigh* test that if live steam reduced through an orifice was used, the steam became superheated. A test thermometer installed in the steam line showed that at 5 pounds, the temperature rose as high as 280 degrees F. As the builder's trials were carried on with such steam, the results are unreliable as showing plant capacity. The superheated steam gives a temperature range in the first effect even greater than that for a high pressure evaporator and much greater than for normal operation. Consequently, the plant shows a capacity much above that possible with wet steam. Scaling, of course, will shortly result and cut the output radically.

Ship	Type	Effects	Steam	Water gals. per hour	Sal. Grs. per gallon	Water per Pound of Steam	Remarks
Utah	Lillie	Double	Pounds About 8	800	.5	Not measured	Feed steam used in one feed heater
Utah	Lillie	Double	3 to 5	605	.5	Not measured	"
Florida	Lillie	Double	About 8	950	Unknown	Not measured	"
Florida	Lillie	Double	About 3	700	Unknown	Not measured	"
Maryland	Lillie	Triple	About 1	400	1.0	Unknown	Just scaled
Maryland	Lillie	Triple	About 4	900	1.0	Unknown	Just scaled
Maryland	Lillie	Triple	About 5	500	1.0	Unknown	After 1 week
Colorado	Lillie	Quadruple	4	850	.8	Not measured	Service results
Raleigh	Lillie	Double	0	650	Varying	1.56	Yard test
Raleigh	Lillie	Double	5	850	.5	1.50	Yard test
Denver	Submerged	Double	3.0	950	.3	1.64	Yard test
Denver	Submerged	Double	3.2	949	.29	Not measured	7 weeks average
Denver	Submerged	Double	3.5	850	.27	Not measured	Over 3 months period*

*Plant scaled once in this interval.

no night watches. The production of fresh water is five (5) times that of the old plant. The operators have had few mishaps due to inexperience. The units of the plant are all in excellent condition and no difficulty has been encountered in their successful upkeep.

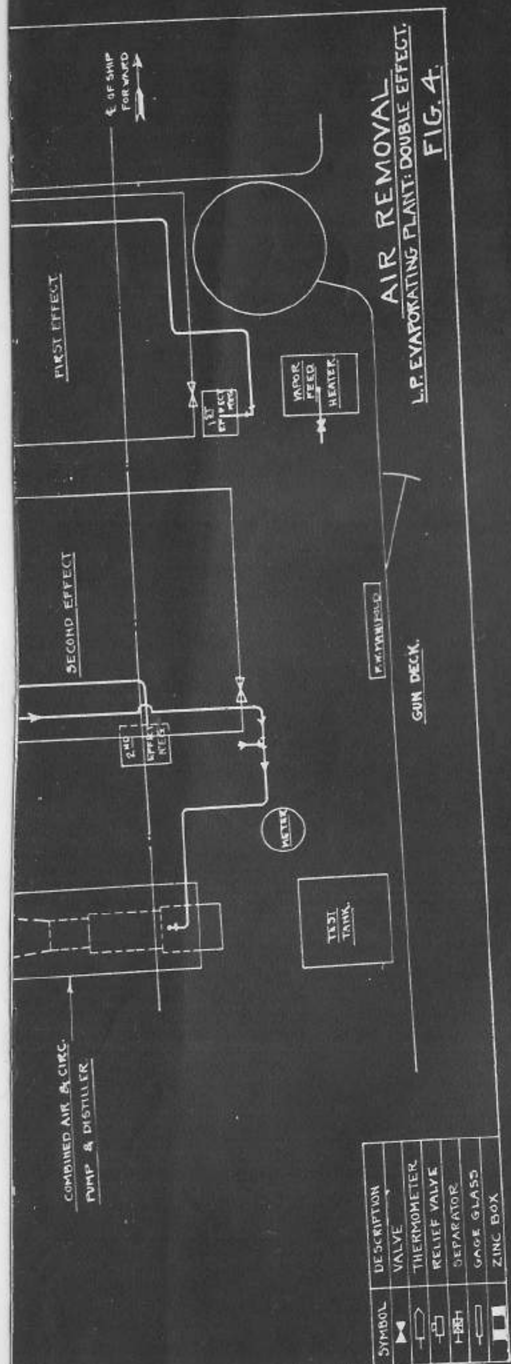
"The coal consumption in port has been reduced from 9.3 tons per day to 7.4 tons per day.

W. N. Jeffers."

The following advantages of the submerged type have now been demonstrated in service:

(*a*) Lesser installation cost, due to fewer units.
(*b*) Lesser operating cost.
(*c*) Greater simplicity and superior reliability of operation.
(*d*) Greater thermal efficiency.
(*e*) Greater capacity.

In view of these results, it appears that the submerged coil type as developed at the Boston Navy Yard and installed on the U. S. S. *Denver* has a marked superiority of performance over other low pressure types being installed in the Navy, and that for future installations, whether on new vessels or conversions of existing high pressure plants, the submerged coil type is preferable.



AIR REMOVAL
L.P. EVAPORATING PLANT: DOUBLE EFFECT.
FIG. 4.

L
11:00 A. M. FR

Hour	Meter	Water per hour gals.	Salin- ity	Brine Con.	Steam Temp. Deg.F.	Pressures or vacua #1 Coil	#1 shell vac.	#2 coil vac.	#2 shell vac.	Conden- ser vac.	Inje- tio
11 am	6420		.3	2.5	203	5"	17		20.5	24.3	
Noon	7070	650	.3	3.25	214	1"	11	17.7	26	25.5	33
1:30 pm	8460	Ave.	.3		204	5"	11	15	24	24.5	33
2:30	9360	per	.3	4.5	220	1#	11	17.5	25	25.5	34
3		hour									
4	10670	900	.2	3.5	220	1.5#	11	17	25	26	34
5	11620	950	.3	4.5		2.5#	8	15	25	25	34
6	12450	830	.3		220	3#	9	15	25	25	34
7	13350	900	.3	3	220	2.5#	10	18	25	26	34
8	14350	1000	.3	3.5	230	5.5#	6	15	24	24	34
9	15360	1010	.2	3.7	230	5#	8	15	25	25	33
10	16320	960	.2	4.	225	4#	6	15	23	24	34
11	17320	1000	.4	3.	228	5#	9	17	25	25	34
Mid.	18320	1000	.3	3.5	220	3#	9	17	25	26	35
1 am	19270	950	.5	2.75	224	3#	5	15	24	26	32
2	20280	1010	.2	3.70	220	4#	9	17	25	26	32
3	21360	1080	.3	3.5	220	4#	9	16	25	25	32
4	22250	990	.3	2.70	220	4#	9	19	25	26	32
5	23350	1100	.4	2.5	222	4#	9	17	25	26	32
6	24350	1000	.2	2.5	222	5#	8	15	24	25	32
7	25220	870	.2	2.7	224	3#	6	15	24	25	32
8	26290	1070	.2	2.5	230	6#	9	18	25	25	34
9	27290	1000	.3	3.5	230	6#	10	19	25	26	34
10	28230	940	.3	4.5	230	6#	7	15	25	26	32
11	29300	1070	.2	4.0	220	4#	8	16	25	26	32

Production, water 24 hours 22880 gallons
Production, water per hour average 953 gallons
Salinity, average .284

Steam consumption for operation of all evaporating plant auxiliar

U. S. S. DENVER
. P. EVAPORATOR LOG SHEET
IDAY FEB. 1 TO 11:00 A.M. SATURDAY FEB. 2

Temperatures - Degrees F						Exhaust steam used						
						Meter Readings						
Over-board Disch.	Heater Disch.	Feed	Brine Disch.	#1 coil drain	#2 coil drain	cu. ft.	cu.ft. per hour	gal. per hour	True	Fresh water, made	Ratio of water to steam	Hour
66	119	123	137	167	144				Meter			11 am
68	161	150	128	175	160				Constant			Noon
70	152	150	144	199	166				- 1.37			1:30 pm
74	161	175	146	198	165							2:30
												3
64	152	154	98	198	154							4
80	144	149		188	156							5
80	142	148		187	159							6
78	145	150		192	144							7
92	158	162		180	154							8
82	160	180	148	180	130	302						9
96	172	178	155	205	168	359	57	427	585	960	1.64	10
84	140	152	150	198	154	420	61	457	626	1000	1.59	11
72	160	164	142	200	155	477.5	57.5	431	590	1000	1.69	Mid.
104	195	148	150	155	162	534.5	57.0	427	585	950	1.64	1am
72	156	162	138	192	162							2
92	158	160	145	190	155		58.1	435	596.5	977	1.64	3
60	154	160	150	190	150							4
60	162	162	136	205	158			Average for 4 hours				5
84	148	144	162	200	154							6
85	158	162	130	204	156							7
76	154	150	148	210	160							8
64	163	168	120		152							9
89	150	149	150	218	160							10
80	154	160	140	190	154							11

ies. 200 lbs. per hour, or 2400 lbs. of steam per day = 300 lbs. of coal per day (about).