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Dryness of Steam and Priming in Marine Boilers.

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Chairman: J. A. Rhynas (Chairman of Council).

Synopsis.

The paper indicates the reasons why the acceptance of contaminated steam supplies to superheaters is unsatisfactory for marine plant, and goes on to set out the basic principles underlying the causes of wetness of steam.

The methods by which these principles may be applied by designers to practical boilers are illustrated by some examples of the arrangements adopted in modern marine practice to ensure dry steam leaving the drum. Some test results obtained by the Admiralty are also given.

A note on the measurement of wetness of steam is included, together with some remarks on the subject of a specification to cover the acceptable impurities leaving the boiler drum and entering the superheater.

An engineer once said "Why bother about priming? The boiler will work more efficiently anyway". Nothing could, of course, be further from the real truth, yet it is correct to say that the gas temperature leaving the boiler will be lower if the superheater is merely part of the generator heating surface.

The steam turbine is most efficient when it is supplied with steam at the pressure and temperature for which it was designed and it follows, therefore, that if superheat were used in the turbine design, the steam leaving the boiler must be raised to some temperature just high enough to allow for the temperature drop due to cooling and to friction loss between the boiler stop valve and the turbine nozzles.

Given enough weight and space, this temperature can be achieved by a superheater whatever the quality of the steam supplied, and the purpose of this paper is to examine firstly why emphasis is laid upon ensuring dry steam leaving the steam drum and secondly what means can be adopted to achieve this object.

Effect of Moisture Content on Superheaters.

As no marine plant can be operated without some accumulation, however slow, of salts in the boiler, it is obvious that the drops of water passing with the steam from the drum to the superheater must contain the salts present in the boiler water.

As the drops of water are evaporated, the salts crystallize out and are either deposited in the superheater or carried through the superheater and subsequently deposited either in the steam pipes or the turbines. If the salts are deposited in the superheater a scale will usually be formed at a bend where the change of direction of the steam flow causes the centrifugal force necessary to throw the salt particle out to the tube wall. If priming continues unchecked, scale deposition will continue until either the superheater tube is choked or the reduction in the heat transfer rate due to scale is sufficient to cause overheating and failure of the tube.

These effects, however, are by no means the only ones, as local corrosion of the superheater tubes due to chlorides is not unknown, particularly near the inlet ends; and if the priming is intermittent the temperature fluctuations of the tube wall may well be sufficient to induce fatigue failure of the "crazy cracking" type, with ultimate perforation and tube leakage.

Effect of Moisture on Steam Pipes and Turbines.

Apart from corrosion and the possibility of corrosion fatigue, no serious effects are likely to arise due to the deposition of salts in steam pipes. In severe cases, however, the operation of valves may be adversely affected and packing may be damaged due to salt penetration on raising steam.

Governor valves of auxiliary turbines are particularly prone to a slow deterioration in performance due to scale accumulation on the valve faces.

Turbines may suffer in two ways from scale deposition, firstly a drop in efficiency due to the changing shape and increased friction of the steam passages, and secondly, some materials used in turbine blade and nozzle construction are susceptible to intercrystalline attack by chlorides. Hence blade or nozzle failures may be experienced in the engines due to bad boiler design or operation.

The Causes of Priming.

There appear to be three ways in which water can be carried into the superheater; firstly by carryover, *i.e.* entrainment of water drops by steam rising from the surface; secondly by foaming, *i.e.* the persistence of the bubble formation and, thirdly, by mal-operation. The last is outside the scope of this paper.

At advanced pressures (c. 2,000 p.s.i.) appreciable quantities of solids can pass directly into solution in the steam without the presence of water. This problem is not yet affecting marine designs but as steam conditions advance it should not be forgotten, as it has already been met in land power stations.

Mechanics of Carryover.

In the simplest case, *viz.* that of pure water, the carryover of water particles with the steam was first examined mathematically by Davis (proc. of Inst. Mech. E., Vol. 144 p. 198). He obtained the formula:—

$$H=\frac{q^2}{2g}\left[\log_e\left\{1+\frac{(p-c)^2}{q^2}\right\}-\log_e\left\{1-\frac{c^2}{q^2}\right\}\right]$$
$$+\frac{cq}{g}\left[2\tan^{-1}\left\{\frac{p-c}{q}\right\}+\log_e\left\{\frac{q+c}{q-c}\right\}\right]\ \ldots\ldots\ldots\ldots\ldots\ (1)$$

where H is maximum height reached by drop in cms.
q is terminal velocity of drop, cms./sec.
c is the vapour velocity rising from surface, cm./sec.
p is velocity of projection of drop, cm./sec.

From this result, the height reached by a drop of water projected from the surface can be calculated for varying rising steam velocities and hence a carryover velocity, *i.e.* the velocity of rising vapour sufficient to entrain drops, may be deduced. Davis estimated that $p=140$ cm./sec. at all boiler pressures.

Figs. 1 and 2 show these curves.

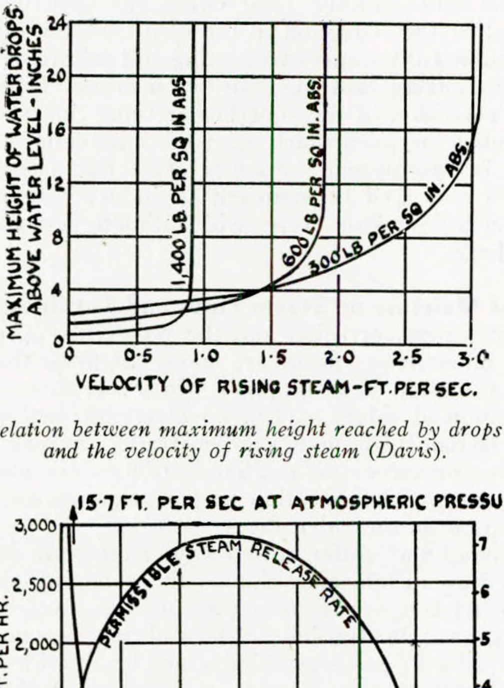


FIG. 1.—*Relation between maximum height reached by drops of water and the velocity of rising steam (Davis).*

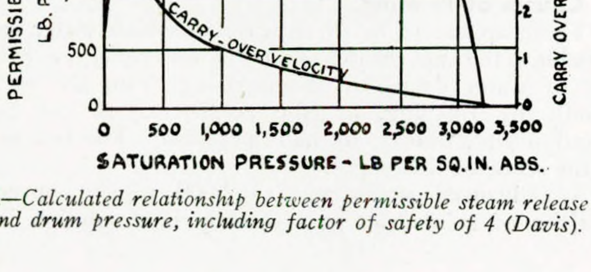


FIG. 2.—*Calculated relationship between permissible steam release rate and drum pressure, including factor of safety of 4 (Davis).*

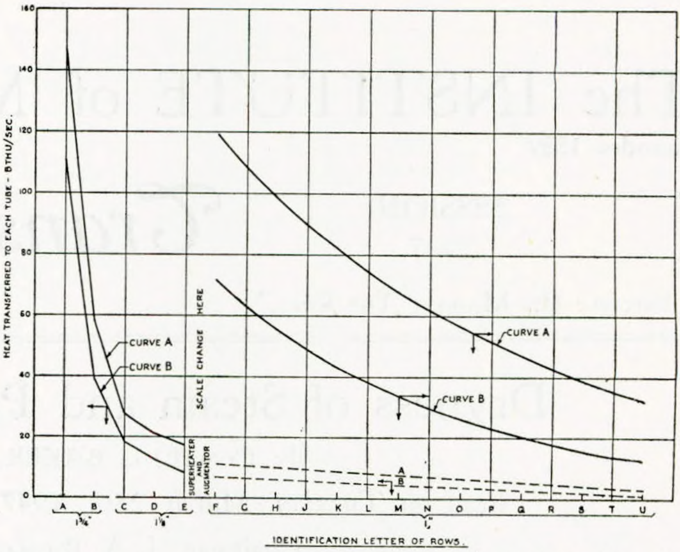


FIG. 3.—*Heat transferred to individual tubes in Admiralty three-drum boilers. Curve A calculated at 61lb./hr. ft.² and curve B at 48·3lb./hr. ft.²*

In his analysis, Davis introduced a factor of safety of four to allow for the unknown factors in the drums of the boilers within his experience. This was intended to take account of possible errors in assumptions, variations of release rate over the drum water plane, etc. In Admiralty boilers, however, an analysis of the heat transferred to the various rows showed that by far the largest proportion of the heat was transferred to those rows (usually the first four

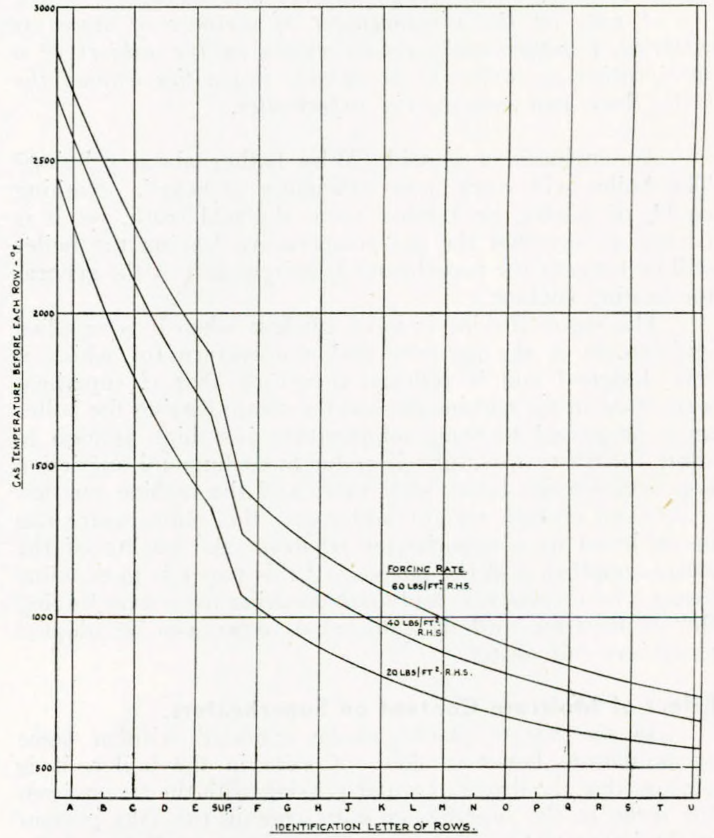


FIG. 4.—*Variation of gas temperature entering each row of tubes of Admiralty three-drum boilers at different radiant heating surface ratings.*

or five) discharging inside the augmentor, and trial results were analysed on the assumptions that all the steam was released inside the augmentor and that the release was uniform over that area, *vide* Figs. 3 and 4.

It was found that results from some five shore trials and all available data from sea confirmed that Davis' results were nearly exact *without the factor of safety of four*; in other words, the release rates calculated to cause carryover did cause carryover. From the available data, the curves given in Fig. 5 were constructed. Exception may be taken to the use of straight lines for the wetness resulting, but in the absence of a larger mass of reliable data it was considered that the straight lines were as good a representation of the results as curves, and experience of using them over four years is completely satisfactory. Such evidence as exists suggests that the slope increases after 5 per cent. wetness has been reached, but this is not important as boilers should not be designed to operate in this range.

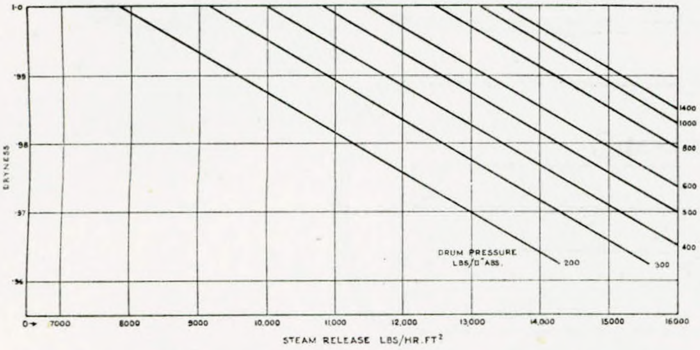


FIG. 5.—*Relation between steam dryness drum pressure and the steam release rate calculated on the net water plane area.*

How will the use of impure water affect these conclusions? Obviously the effect will be dependent upon the influence of the impurities on the values of the constants p and q in the equation (1).

q is calculated from :—

$$q = 12{\cdot}35 \sqrt{\frac{\rho - \rho^1}{\rho^1}} . d_0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where d_0 = drop diameter $\propto \left\{ \frac{\gamma d^2}{\rho} \right\}^{\frac{1}{3}}$

d = bubble diameter.

ρ = liquid density.

ρ^1 = vapour density.

γ = surface tension of liquid.

$$\text{and } p \propto \left(\frac{\gamma}{\rho r^2} \right) \doteq 140 \frac{\text{cm.}}{\text{sec.}} \text{ at all boiler pressures } \ldots\ldots\ldots \quad (3)$$

where r = radius of dome of bubble.

Substituting in equation (1)

$$q = a. [\gamma]^{\frac{1}{3}}$$
$$p = b. \gamma$$

we obtain :—

$$H = a^1. \gamma^{\frac{1}{3}} \left[\log \left\{ 1 + \frac{(b\gamma - c)^2}{a^2 \gamma^{\frac{1}{3}}} \right\} - \log \left\{ 1 - \frac{c^2}{a^2 \gamma^{\frac{1}{3}}} \right\} \right]$$
$$+ c a^{11} \gamma^{\frac{1}{3}} \left[2 \tan^{-1} \frac{(b\gamma - c)}{(a\gamma^{\frac{1}{3}})} + \log \frac{(a\gamma^{\frac{1}{3}} + c)}{(a\gamma^{\frac{1}{3}} - c)} \right] \quad \ldots\ldots\ldots\ldots \quad (4)$$

where a, b, a^1, a^{11} are constants.

From inspection of the above, it is obvious that the variations in the projection height H with surface tension is slight. To this must be added the fact that normal concentrations of solids cannot increase the surface tension more than 1 per cent. (Davis *loc. sit.*). Hence the effect of the normal impurities in a boiler is very small and they cannot influence carryover to any great extent.

Variation of Release Rates in a Boiler Drum.

The local rate of steam generation will vary over the drum surface with the local rate of heat transfer which in turn varies in the following ways :—

(*a*) The transfer rate decreases from the furnace to the uptake, those tubes that "see" the furnace producing the majority of the steam.

(*b*) The distribution of heat transfer varies with the furnace rating and G.H.S. rating.

(*c*) For the first three feet from a burner the rate of heat generation is appreciably less than that arising in the next three feet; thereafter the heat release is fairly constant until in long boilers a drop is gradually experienced as the flame ceases to burn luminously and the cross flow of the gases takes them into the tube bank.

(*d*) With end-fired boilers the velocity of oil and air along the furnace will tend to load the back of the furnace more than the front. This is particularly the case with angled burners. With side-fired boilers the furnace loading at reduced outputs may be appreciably higher locally owing to the restricted spread of the flame from one or two burners.

It follows from the above that if an internal dry pipe is not fitted, and all available evidence tends to show that it can serve no useful purpose in most boilers, the offtake should be situated in the first three feet of the drum of an end-fired boiler. In this way it will be less directly exposed to high release rates.

In general the offtake should be on the crown of the drum in order to get the maximum height under all conditions. In a few cases this is not possible and preference should then be given to siting the offtake over the side remote from the highest release rates in order to increase the distance the steam has to travel.

None of these remarks applies of course in a design embodying cyclone separators, *q.v.*

Mechanics of Foaming.

There is, however, another effect of both free solids and solids in solution, organic matter, etc., *viz.* the stabilisation of foams, *i.e.* the failure of the steam bubbles to burst on reaching the surface. This property is explained by different scientists in a number of ways and agreement is far from universal. However, for engineers this is unimportant as the essential factors are clear, *viz.* that the stabilisation of foams is not a property of a single chemical or group of chemicals, nor is it a function of a single property of a given chemical or group of chemicals. The problem is linked with that of the stability of individual bubbles which in turn depends upon the action of the molecular layers forming the "skin" of the bubble. Stable foams are formed when the properties of the skin of the bubble differ from the bulk of the fluid, *i.e.* when the salts in solution are adsorbed either positively or negatively.

Alkalis, chlorides, etc. commonly found in boilers will form stable foams if the concentration is sufficient, whilst some organic materials, *e.g.* saponin, may cause trouble due to foaming much more easily. These organic materials are often present in shore waters and may be picked up by distillation from sea water that is contaminated by the

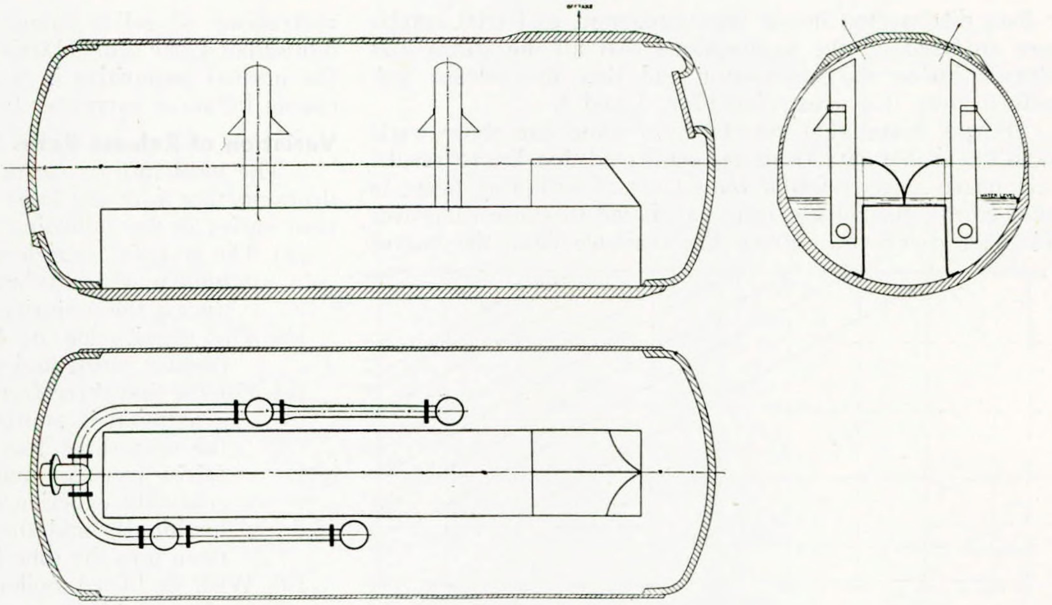


FIG. 7.—*Typical diagrammatic arrangement of the modified circulation augmentor fitted in the latest Admiralty three-drum boilers, showing the feed pot system of internal feed water distribution.*

discharge from rivers, etc. Saponin is frequently met in tropical and sub-tropical climates and has been known to cause the turbines of a ship to be completely choked with salts carried over by the formation of foams. On the other hand, some organic substances possess the opposite property and suppress the formation of stable foams, even when conditions are in all other respects favourable. Either property may be possessed to a degree bearing little relation to the actual concentration of the substance in the boiler water.

So far as practical boilers are concerned, the liability to form stabilised foams depends upon :—

(*a*) Alkalinity.

(*b*) Total solids in solution.

(*c*) Total solids in suspension.

(*d*) Organic matter present.

Some practical experience with boiler waters will be given later, but a rigorous treatment is not yet possible as the scientific background is not conclusive.

Conclusions.

(1) Carryover is purely a mechanical problem and is, therefore, subject to design.

(2) Foaming is a chemical problem and is subject to chemical design of the boiler water treatment.

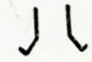
The curves in Fig. 5 indicate the limiting release rates that may be expected to obtain in those cases where the release area can be clearly defined. Where the area is not known, a factor must be introduced to suit the particular design of boiler, but care must be taken not to place more reliance on this empirical factor than the practical experience with its use justifies.

The limits on foaming do not appear to be clearly defined and are, in any case, so modified by other factors that no precise limit can be stated.

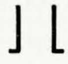
Admiralty Practice and Experience.

Before passing to a resumé of the basic types of internal fittings, it may be of interest to record a number of results obtained by the Admiralty in the war years.

Design of Augmentor.

As is probably well known, the majority of high-output boilers designed by the Admiralty during the war were equipped with the augmentor invented and described by Admiral Dight. The original designs were to some extent limited by the arrangement of tube nests, as in order to avoid impeding the flow of water in the E-row tubes, it was customary to make the augmentor  -shaped (*vide* Fig. 6). Considerable wetness was experienced in a number of designs at 300 p.s.i. and high ratings. In one particular case, the steam temperature realised on trials was 520° or 130°F. below the design.

Consideration of Davis's results and Fig. 5 suggested that modifying the augmentor to  should result in about 110° improvement in steam temperature, and this was in fact obtained on trials under comparative conditions at sea.

Somewhat before this experience, it had been agreed to fit the *Vanguard* boiler with a  -augmentor for trial, Fig. 7, and in 1943 the trials confirmed the theory to the full, no wetness being experienced under normal operating conditions up to the full

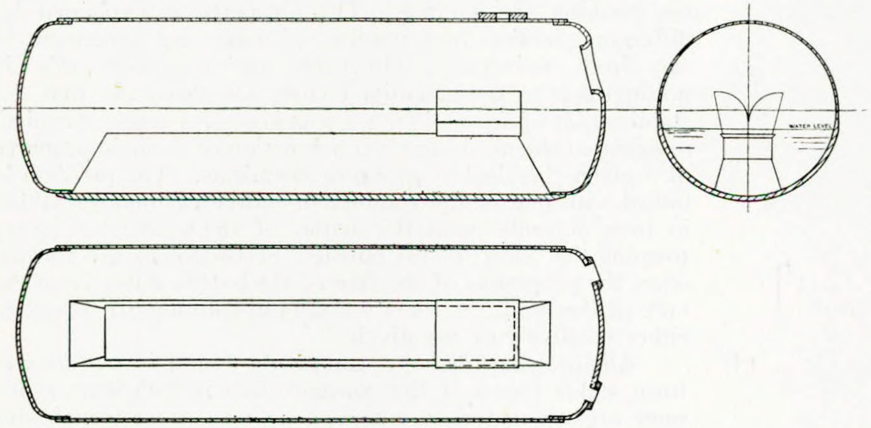


FIG. 6.—*Typical diagrammatic arrangement of circulation augmentors fitted in Admiralty three-drum boilers; a number of arrangements of internal feed pipes are fitted with this design.*

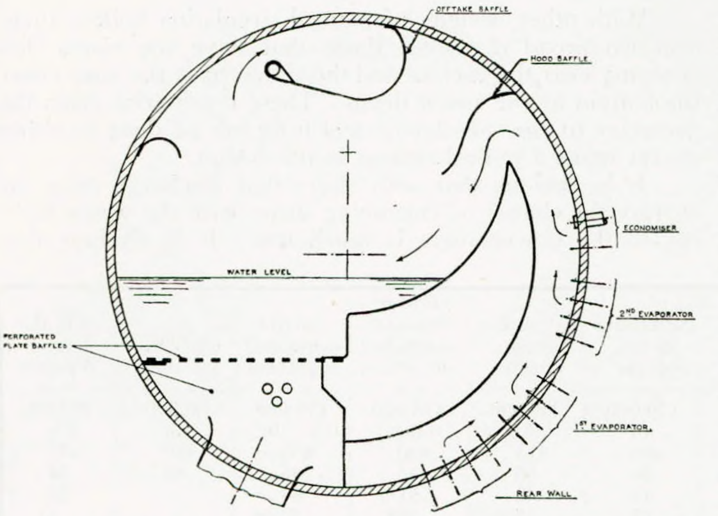


FIG. 8.—*Arrangement of internal baffles in the La Mont S.G.B. boiler.*

designed overload. With an alkalinity of 0·7 per cent. N and a total solid content of 2,800 p.p.m., priming occurred at a relatively low rating.

Neither 0·7 per cent. N alkalinity, nor a total solid content of 2,800 p.p.m. *alone* produced priming, but both together did. It is considered, therefore, that the foaming was probably slight and only just sufficient to bring the projected particle into the higher velocity streams near the offtake.

As a result of these experiences, it was agreed that augmentors should be modified in existing ships and the author carried out the modification in some boilers of the aircraft carrier H.M.S. *Victorious.* About 30° F. rise in steam temperature was obtained at high powers, again in accordance with theory.

At sea an alkalinity of 1·0 per cent. N began to show evidence of slight priming at the higher outputs, even when the chloride content was very low.

The Steam Gun Boats.

The steam gun boats were interesting because of the special lightweight designs of machinery and boilers fitted. The La Mont forced-circulation boiler weighed only 0·47lb. per lb. output at 400 p.s.i. and 700° F. It had a 36in. steam and water drum.

The Foster Wheeler modified D-type boiler for the same class weighed 0·52lb. per lb. output and had a 33in. steam drum.

Both these designs then had drums much smaller than the conventional Admiralty boiler with its 50 or 56in. drum.

As might be expected both designs were sensitive to operating conditions, yet the record of achievement is quite convincing.

On shore trials, after modification of the drain from the offtake, dry steam was obtained from the La Mont boiler up to 80,000lb. per hr. This was also obtained on service, but the excessive squat of the vessels, due both to unexpected loading and to speed, required further modifications to the "hood" baffle, as the clearance for the water under these conditions was too small for free passage of the steam-water mixture leaving the baffle, Fig. 8.

The Foster Wheeler boiler was fitted with perforated plate baffles, Fig. 9, and was very sensitive to squat. When originally tested an output of 70,000lb. per hr. was obtained without wetness and the figure never fell below 40,000lb. per hr., even under the worst conditions. Due to the small drum, this design was troubled by the varying head over the baffle plates, particularly when the upper plate began to be uncovered. As might be expected under these conditions, the baffle ceased to act and priming due to carryover occurred. The wetness on service, however, did not exceed 3 per cent. at overload.

Design Criteria.

From the above analysis of carryover, it is apparent that two factors are involved, firstly the loading of the release surface and, secondly, at low drum pressures the provision of adequate clearance above the surface so that the increasing velocity of rising steam near the offtake does not entrain moisture.

These two are separate and cannot be combined as the safe height varies with different pressures, *vide* Fig. 1. Hence ratings based on the volume of the steam space can only be of value in designs of similar types of boiler.

The criteria for foaming should not arise under normal operating conditions as the margins appear to be large enough to ensure safety. The usual practice is for the

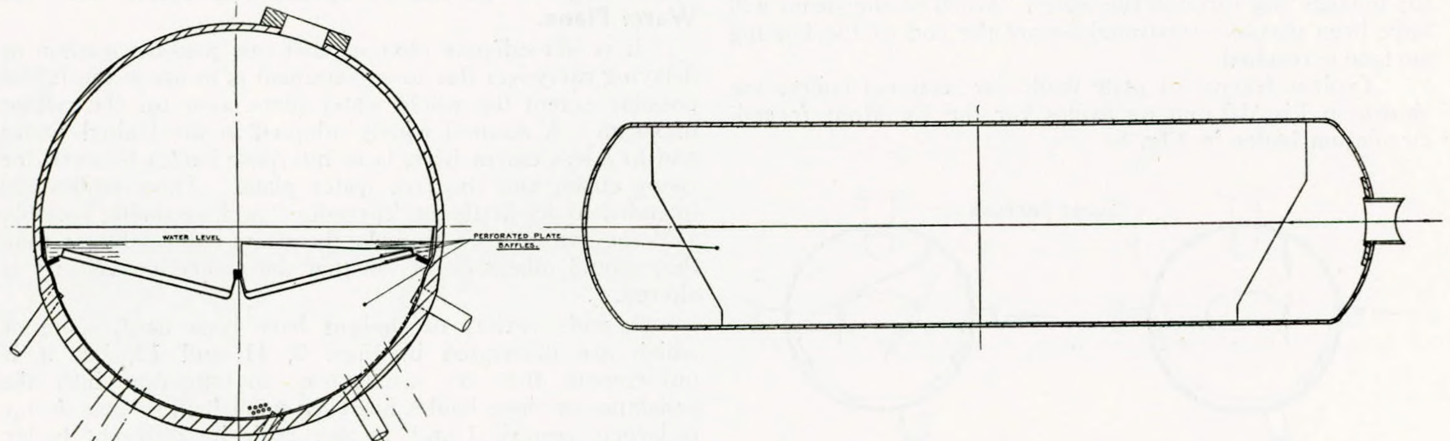


FIG. 9.—*Arrangement of internal perforated plate baffles in Foster Wheeler S.G.B. boiler.*

boiler designer to recommend the water treatment including total solids and alkalinity. These figures are empirical and must remain so pending a more detailed investigation of the influence of the various factors under operating pressures and temperatures.

Influence of Wetness considerations on Design of Boilers.

The boiler heating surface has usually been drawn to fit some arbitrary conventions, determined by geometry or the designer's eye, and for the most part the results have not been unsatisfactory.

The possible methods of overcoming priming in boilers are:—

(1) Design of the heating surface.

(2) Design of baffles to spread the steam over the whole surface.

(3) Design of centrifugal or other methods of increasing the effective surface area for release.

(4) Design of centrifugal or other means of separating the moisture from the steam after it has reached the offtake.

(1) Design of Heating Surface.

The sectional boiler discharged the steam-water mixture from the return tubes above the still water surface in the drum and is, therefore, comparable with the forced-circulation boiler where the arrangement of tubes is purely one of convenience.

With these arrangements the volume of water present in the steam-water mixture will be from 5-30 per cent., depending upon other conditions; it is obvious that the size of steam bubbles will be large and that separation from the water will be a different problem from the case in which the bubbles rise through the water. Much of the steam will have been partially separated before the end of the heating surface is reached.

Typical designs of plate baffle for sectional boilers are shown in Fig. 10 and of baffles for the La Mont forced-circulation boiler in Fig. 8.

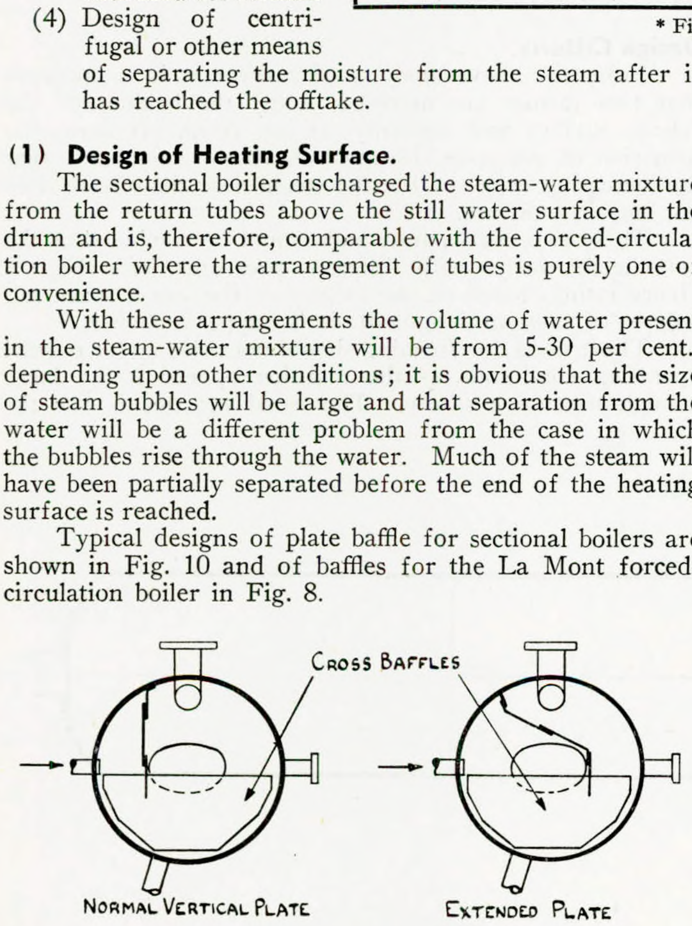


FIG. 10.—*Typical arrangements of plate baffles fitted in sectional boilers.*

With other designs of natural-circulation boilers there are two broad divisions, those that have the risers discharging near the surface and those that have the risers near the bottom of the steam drum. These types arise from the geometry of the tube layout and little can be done to either except make a radical change in the design.

It is obvious that with risers that discharge near the surface the chance of entraining steam with the water flowing to the downcomers is much less. It is obvious that if the risers enter near the water surface, the downcomers will have the maximum head over them at all times, thereby increasing any margin of safety there may be.

Boiler		Admiralty three-drum	Admiralty three-drum	Foster Wheeler controlled superheat	Yarrow controlled superheat	S.G.B. La Mont	S.G.B. Foster Wheeler
Output	lb./hr.	170,000	200,000	175,000	175,000	80,000	80,000
Max. wetness	—	nil	0·5%	0·66%	0·8–1·0%	nil	3%
Drum pressure ...	p.s.i.	420	415	400	430	450	435
Drum diameter ...	ins.	56	56	50	56	36	34
Gross water plane *GP*...	ft.^{2}	45	46	51·5	64	—	22
Net water plane *NP* ...	ft.^{2}	17	17·9	25*	23·5*	—	6*
Mean release rate on gross area	$\frac{\text{lb.}}{\text{hr.ft.}^2 GP}$	3,778	4,350	3,400	2,740	—	3,637
Mean release rate on net area	$\frac{\text{lb.}}{\text{hr.ft.}^2 NP}$	10,000	11,170	7,000*	7,450*	—	13,333*
Volume of steam space	ft.^{3}	115	120	106	88	23	30·3
Volume rating... ...	$\frac{\text{ft.}^3}{\text{hr.ft.}^3}$	1,585	1,800	1,850	2,080	3,470	2,725
Height of orifice above water level	ins.	34	34	25½	28¼	17	16

* Figures estimated by inspection of drawings.

Admiralty practice with three-drum boilers has for the most part been to fit as few drum internals as possible in order to avoid complication, but it is apparent that the increasing ratings of boilers will necessitate some modification of this policy. Fortunately, the use of a phosphate boiler water treatment reduces the need for internal cleaning very considerably, so that greater complication can be accepted. The problem is by no means so severe in the majority of merchant ship designs.

(2) Design of Baffles to Spread the Steam over the Water Plane.

It is immediately obvious that one possible method of delaying carryover due to entrainment is to use to the fullest possible extent the whole water plane area for the release of steam. A method widely adopted in the United States and to a less extent here, is to interpose baffles between the rising steam and the free water plane. These baffles are intended to act firstly as "spreaders" and, secondly, possibly as "coagulators"—*i.e.* to make the steam bubbles larger than they would otherwise be, so that the projection velocity is altered.

A wide variety of designs have been used, some of which are illustrated in Figs. 9, 11 and 12, but it is unfortunate that no satisfactory investigation into the resistance of these baffles has been published, so that design is largely empirical and, in any radically different boiler, tests are necessary to ensure satisfactory performance.

As previously indicated, these baffles are sensitive to water level and for marine work their design does not seem

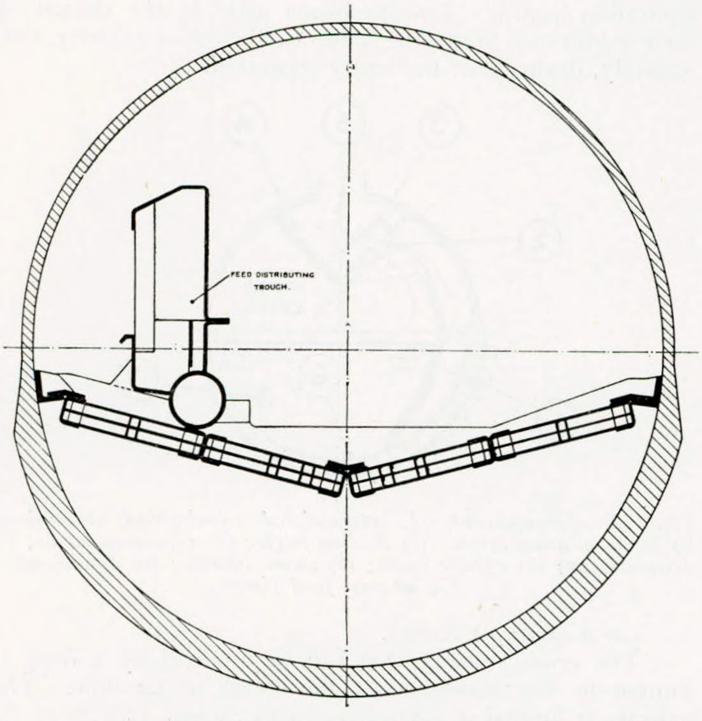


FIG. 11.—*Arrangement of perforated plate baffles in Foster Wheeler controlled superheat boiler.*

to meet all the requirements. However, in most designs an arrangement of plate baffles can be made to meet the most rigorous specifications in use at the present time.

(3) Design of Centrifugal or other Methods of Increasing the Effective Surface.

These baffles aim, by means of increasing the effective surface of the release area, at separating the steam and water at a low enough rate to ensure that entrainment cannot occur.

In both practical cases, the risers are pocketed off from the rest of the drum so that the steam-water mixture must pass through the baffles. There, however, the similarity ends. In the case of the "cyclone" separator, Figs. 13 and 14, the steam-water mixture enters a vertical cylinder tangentially, steam separates from the vortex formed and rises through the scrubber, whilst the water is ejected from the cyclone into the water space by its own velocity head. A number of such cyclones adequate for the output of the boiler are fitted.

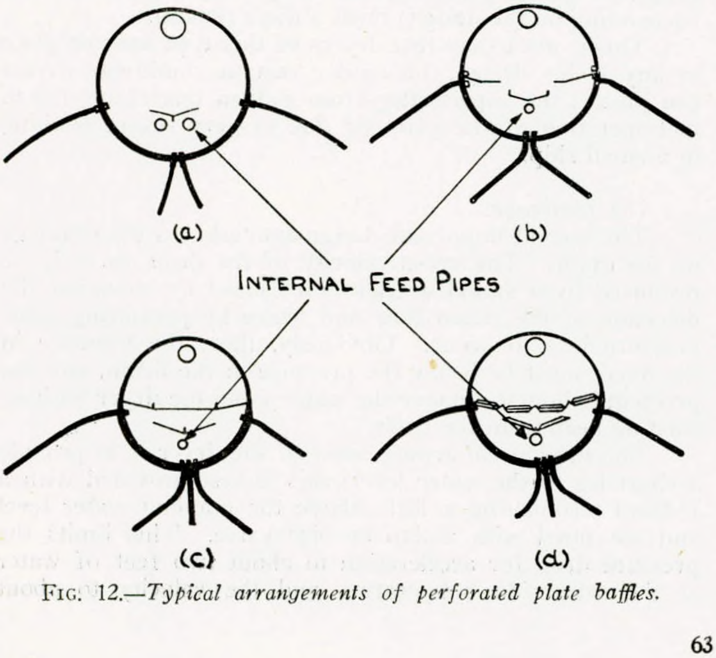


FIG. 12.—*Typical arrangements of perforated plate baffles.*

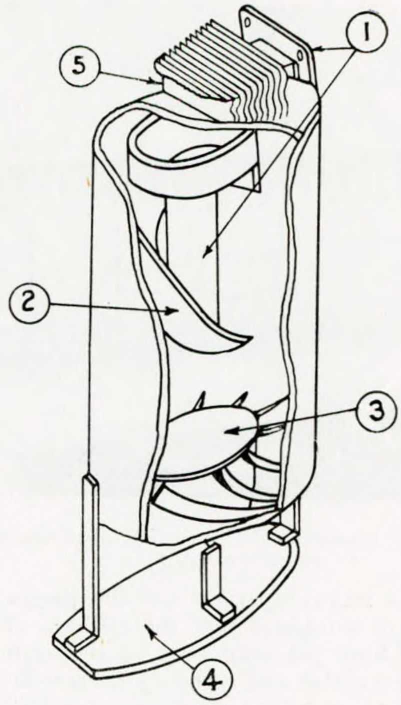


FIG. 13.—*Part sectional details of Babcock & Wilcox cyclone separator. (1) Inlet; (2) entrance plate; (3) vane outlet; (4) splash plate; (5) steam scrubber.*

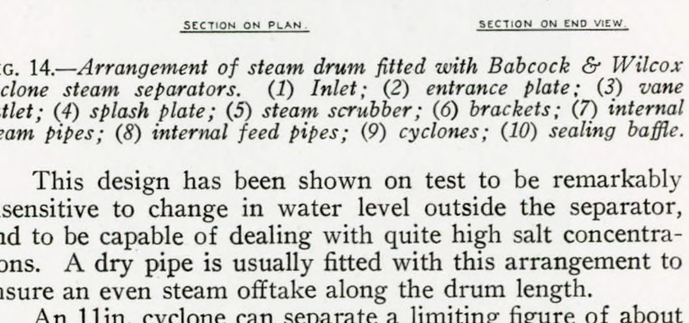


FIG. 14.—*Arrangement of steam drum fitted with Babcock & Wilcox cyclone steam separators. (1) Inlet; (2) entrance plate; (3) vane outlet; (4) splash plate; (5) steam scrubber; (6) brackets; (7) internal steam pipes; (8) internal feed pipes; (9) cyclones; (10) sealing baffle.*

This design has been shown on test to be remarkably insensitive to change in water level outside the separator, and to be capable of dealing with quite high salt concentrations. A dry pipe is usually fitted with this arrangement to ensure an even steam offtake along the drum length.

An 11in. cyclone can separate a limiting figure of about 14,000lb. per hr. of steam at 600 p.s.i. with less than 0·25 per cent. residual wetness.

With the other design, the increased effective surface is obtained by means of "hoods", Figs. 15, 16 and 17, which divide the steam-water mixture into a number of broad jets

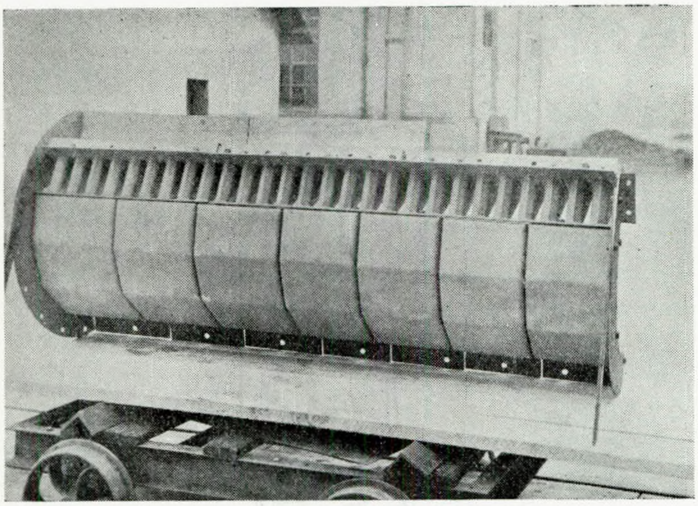


FIG. 15.—*View of International Combustion steam-drum baffle from the generating tubes.*

from which the steam separates out and passes up between the jets through scrubbers into the offtake. No test data of this design have yet been seen by the author, but it is stated to be successful and certainly no reason is seen why it should not be.

(4) Design of Dryers.

The basic error of all "dryers" is that it is fundamentally wrong to start what you cannot stop! In other words it is better to prevent the steam being wet than to let it be wet and then try to dry it.

Most dryers work on the principle of providing a cross velocity by tangential swirl in a cylinder or by a labyrinth; this cross velocity causes the water droplets to move across the fluid stream towards the restraining boundary where separation occurs. Two problems arise in the design of such separators, firstly the value of the cross velocity and, secondly, drainage of the water separated.

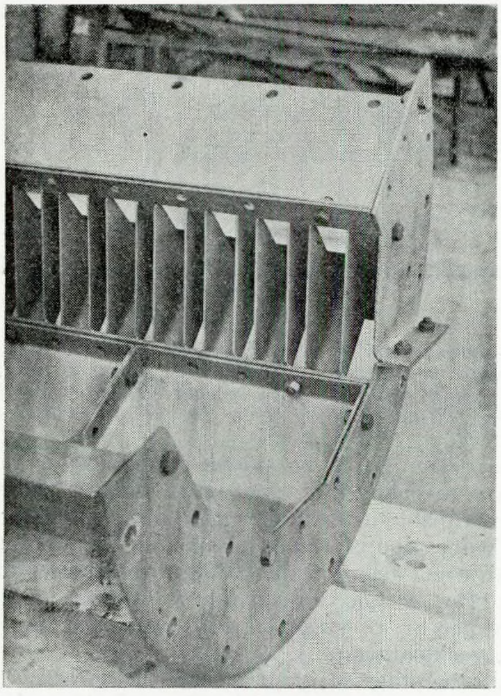


FIG. 16.—*View of International Combustion steam-drum baffles from inside drum.*

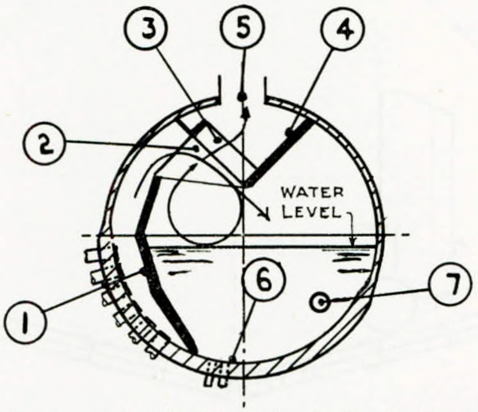


FIG. 17.—*Arrangement of International Combustion steam-drum baffles in a steam drum.* (*1*) *Sealing baffle;* (*2*) *reversing hoods;* (*3*) *drier screens;* (*4*) *offtake baffle;* (*5*) *steam offtake;* (*6*) *downcomers;* (*7*) *internal feed pipes.*

(*a*) *Limiting Velocity.*

The cross velocity that can be attained by a drop is limited by the resistance of the steam to its flow. The velocity is limited in accordance with Stokes' Law.

$$V=\frac{2gr^2\ (\rho-\sigma)}{9\mu}$$

where V = terminal velocity
g = acceleration
r = radius of particle
ρ = density of particle
σ = density of fluid
μ = viscosity of fluid

From this it appears that drop size is a major factor in the success or otherwise of dryers of this type. Assuming that drops of a certain size are originally uniformly distributed across the stream, it follows that the percentage of drops separating out will be limited by the time available to travel across the stream. In practice the time available is always less than the time required for separation of all drops, so that a percentage of drops below a certain size (depending on the design) must always remain.

This is not to say that dryers of this type have no place in any boiler design, for under certain conditions dryers can protect the superheater from sudden quenching due to mal-operation of the plant or due to very severe pitching in a small ship.

(*b*) *Drainage.*

The second important design limitation is the drainage of the dryer. The cross velocity of the drop can only be produced by a radial acceleration caused by changing the direction of the steam flow and hence by permitting some pressure loss to occur. Obviously, then, the pressure in the dryer must be below the pressure in the drum, and the problem is how to remove the water from the dryer without wasting heat from the cycle.

The most usual arrangement of the dryer is to provide a short leg to the water level; this is best provided with a U-bend terminating a little above the nominal water level and *not* fitted with a flap or disc valve. This limits the pressure drop for acceleration to about two feet of water at the saturation temperature and the velocity to about

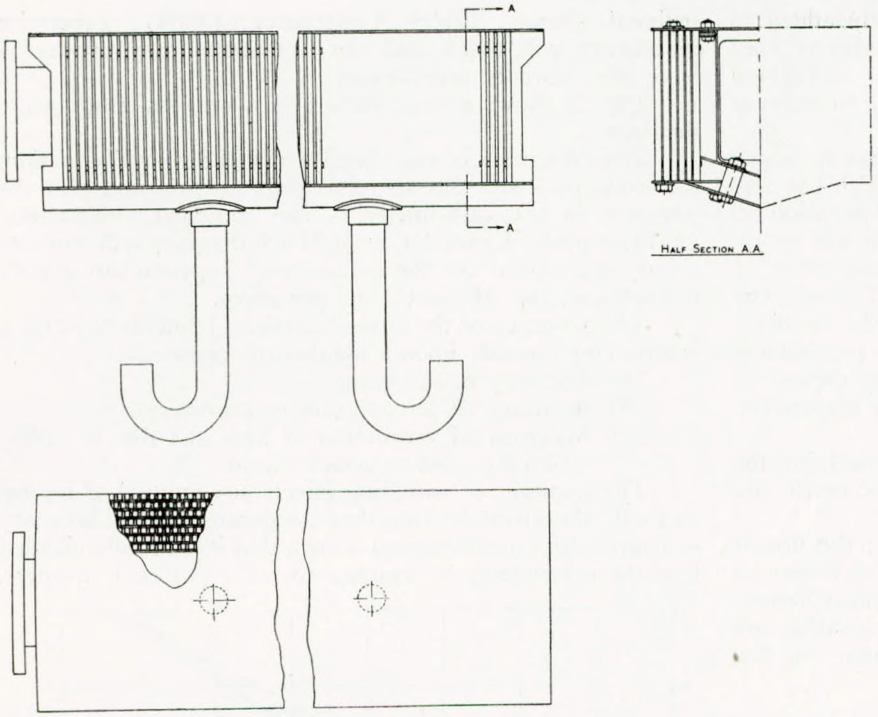


FIG. 18.—*Typical design of a Tracy labyrinth type purifier.*

40-50ft. per sec.

Another method is to site the dryer outside the steam drum and to lead the drain pipe into the boiler again at the water-drum level, either with or without pump assistance. In this way the available drainage head is the difference between vertical distance and the apparent height of the water in the boiler measured at the point of discharge of the drain. This head will vary with the design of boiler and may be as much as six or seven feet, in which case the available velocity would be about 85ft. per sec. With a pump, greater heads can be obtained at the expense of power consumption.

One objection to this method of drying the steam is that the pressure loss through the dryer has to be added to the loss through the superheater, and hence increases the boiler-drum design pressure for a given turbine cycle.

A further difficulty experienced with dryers of this type arises from the space they require to keep the pressure loss low. Even if two or more are fitted in parallel, the loss of clearance above the water level is considerable, and in highly-rated designs it is doubtful whether they can be accommodated satisfactorily within the drum

The construction of one of each type of dryer is shown in Figs. 18, 19 and 20.

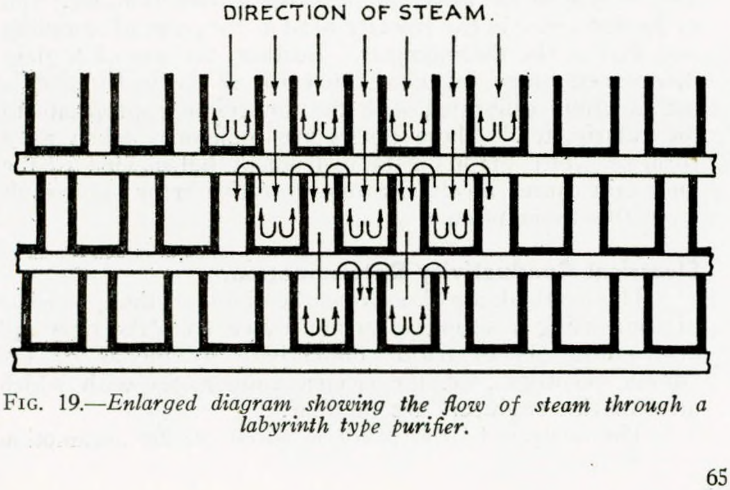


FIG. 19.—*Enlarged diagram showing the flow of steam through a labyrinth type purifier.*

Special Devices for Marine Boilers.

So far, the methods of overcoming carryover have been based on the assumption that the boiler is stationary. Anyone who has been to sea will know that is seldom true! Some of them by nature of their construction provide for rolling or pitching irrespective of the position of the drum, *e.g.* "cyclone", plate baffles, etc.

Where no fittings are provided in the water space, the drum should not be sited athwartships, but, as in sectional boilers, cross baffles to prevent surging along the drum can be used as long as end flow is not an essential part of the circulation of the boiler, *e.g.* end unheated downcomers.

Naval experience does not suggest that the rolling and pitching movement experienced by ships affects the dryness of steam from drums arranged on the fore and aft line to any appreciable extent, but possibly the augmentor has masked the effect in the longer boilers of destroyers during the war. Where this is feared, cross baffles can be used.

In both cases, where end flow is necessary to the correct functioning of the design, perforated cross baffles can be arranged or alternate half baffles can be fitted to restrict the freedom of end flow. In either case, however, the loss of head along the drum may be appreciable and should be taken into account when designing the circulation factor of the boiler.

Measures to avoid Foaming.

As has already been indicated, the problem of foaming is essentially one of the physico-chemical action of the impure water, and the solution to the problem lies, therefore, in an attack from this angle.

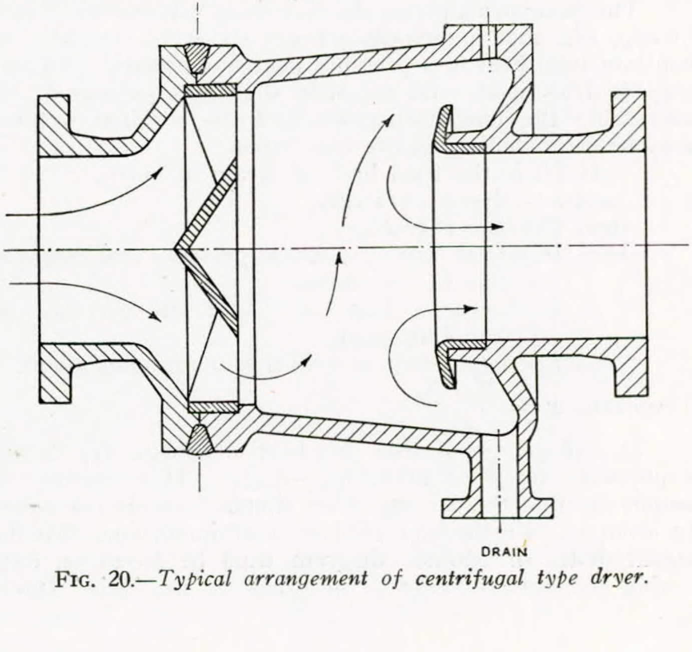


FIG. 20.—*Typical arrangement of centrifugal type dryer.*

To this end, chemicals are not infrequently added to the boiler, either separately or as part of the mixture used for boiler water treatment, to reduce the surface adsorption of the films, thereby ensuring that the tendency to foam is reduced.

Foremost among these chemicals is corn-starch, which is an ingredient of some boiler mixtures and which has also been used successfully for combating scale formation in evaporators. The functions of the corn-starch are firstly the reduction of foaming by its effect on adsorption of solids in solution, secondly the absorption of oil should any be present in the boiler due to mal-operation of the auxiliary plant and, thirdly, to act as a coagulator for the precipitated calcium and magnesium phosphates so that they deposit as sludges, do not form scale and do not remain in suspension. In all these rôles it is very successful.

Other chemicals such as tannin have been used, but the author has no authenticated reports of their successful use under strictly comparative conditions.

A word of caution is, however, necessary: the use of organic substances is to be deprecated at the higher pressures now being envisaged owing to the risk of chemical decomposition that exists. When this occurs, organic acids are liable to be formed and unless the water treatment can deal effectively with them corrosion must ensue.

Measurement of Wetness.

The measurement of wetness presents a considerable problem if accuracy is desired. The usual throttling calorimeter will show the inception of serious priming but is not sensitive enough (particularly with increasing pressure) to show small moisture content; a well-made instrument will give readings accurate to ±0·1 per cent. up to about 5 per cent.

A second method that is widely used in the United States is the estimation of the solid content of the steam by measurement of the electrical conductivity of the condensed water.

Finally, the solids may be measured, and hence the wetness estimated, by weighing the solids left behind after evaporating to dryness a large volume of condensed steam.

Throttling Calorimeter.

The basic principle of the throttling calorimeter is well known, *viz.* that a quantity of wet steam is expanded at constant total heat to a pressure near atmospheric. In this way it dries itself and becomes slightly superheated; by measuring the temperature attained the original wetness may be estimated by simple calculation :—

If H_i is the total heat of steam at entry,
and x = dryness fraction,
then $H_i = h_i + xL_i = H_o$
where H_o = total heat of steam at pressure and temperature of calorimeter
h_i = sensible heat of water at pressure at sampling point
and L_i = latent heat at pressure at sampling point.

Therefore $x = \dfrac{H_o - h_i}{L_i}$

It will be noted that the heat of steam H_o is not expressed as $h + L + 0{\cdot}48(t_{\text{sup.}} - t_{\text{sat.}})$. This serves to emphasize that this or any other simple formula can never be accurate. Furthermore, it is of vital importance that the steam tables or Mollier diagram used be based on data within the agreed limits of accuracy of the Third International Steam Tables Conference (1934); otherwise inaccuracy will result and the wet steam may appear to have been initially superheated!

Fig. 21 shows a small section of a wetness-temperature diagram.

This diagram is calculated from the above equation, assuming no losses due to velocity or friction and that the pressure in the calorimeter is one standard atmosphere, *i.e.* 14·69 p.s.i. Examination of $H - \Phi$ diagram will indicate clearly the reason for the existence of separate but closely related lines for different drum pressures.

The accuracy of the answer obtained from the throttling calorimeter depends upon a number of factors :—

(*a*) Accuracy of sampling.
(*b*) Accuracy of temperature measurement.
(*c*) Accuracy of estimation of heat loss due to radiation etc., and to velocity head.

The accuracy of sampling affects any method of testing and will, therefore, be considered separately. The accuracy of temperature measurement is such that it is usually claimed that the calorimeter is accurate to ±0·1 per cent. wetness. This is not considered high enough and, as the performance falls off with increasing pressure, the author considers that the calorimetric method should be regarded as satisfactory only for qualitative results and not for quantitative results on high pressure units at low wetness figures.

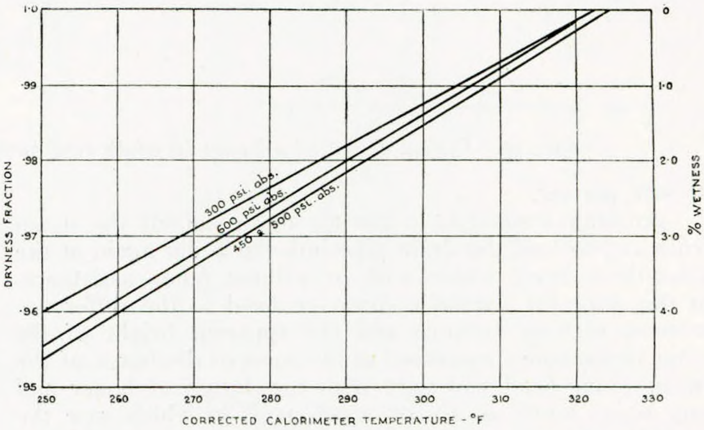


FIG. 21.—*Relation between the dryness fraction of the sample and ideal throttling calorimeter temperature at varying drum pressures.*

It will be found on test that in the majority of cases the wetness figure obtained from a calorimeter is between 0·1 and 0·2 per cent., even when the boiler is not "steaming". This is due to the losses of heat due to radiation, etc., and to the difference in the velocity head at the point of sampling and that at the thermometer. Further, the use of a glass thermometer may introduce an error if the instrument is not carefully calibrated with the immersion appropriate to the calorimeter. These errors are sometimes taken as a form of "zero" error on the instrument, but in view of the uncertain causes involved a more positive error may result from this assumption.

Electrical Conductivity Determination.

This method, also known as the dionic method, consists of condensing a sample of steam drawn from the pipe and determining its electrical conductivity by means of the "dionic recorder", *i.e.* the electric salinometer with which most marine engineers are familiar.

The analysis of the result is based on the assumption that the solids in the wet steam will be in the same proportions as the solids in the boiler drum. From this knowledge, a total solids can be calculated and hence the amount of wetness.

The method can produce accurate results, but it needs considerable care and is by no means as easy as it sounds. Considerable errors can be produced by gases in solution and particular care is necessary to ensure that the metal in contact with the condensate does not cause false readings by metallic contamination of the water.

Gravimetric Determination.

Subject to sampling, this method produces a very accurate value for the weight of solids in the steam, but owing to the length of time it takes to get an answer it is quite unsuitable for determination of the wetness on trials except at specific check periods.

As in the dionic method, the estimation of the priming depends on the assumption that the solids in the steam are in the same proportion as the solids in the drum. Experience on Admiralty trials has indicated that this cannot be assumed with any degree of reliability, but this is nevertheless not a matter of major importance as the nuisance value of priming is centred in the solid content, which can be determined accurately by this method.

Sampling.

The problem of sampling is one of the most difficult of all problems in the measurement of boiler performance. The difficulties arise from the ease with which the distribution of the water particles across the stream of wet steam is disturbed.

Most test codes provide some form of standard design of sampling nozzle which it is recommended shall be inserted in the pipe under test in a suitable position. In most marine boilers under test it is almost impossible to find a suitable position and some compromise is usually necessary. The best position is in a pipe in which the steam is flowing steadily vertically downwards remote from any valve or other disturbing element. The next best is one in which the steam flows upwards. If a horizontal pipe has to be used, the sampling nozzle should be sited immediately after a valve or other mixing device, but even so the sampling cannot be relied upon.

Some authorities consider that the nozzle should be designed to remove the sample from the pipe at the velocity of flow in the pipe, but this principle is frequently not accepted in the standard designs.

Recommended Specification for Wetness.

The specification of wetness is not easy owing to the difficulties of measurement, but there is little doubt that some attempt should be made to specify the wetness, if a completely satisfactory plant is required.

In the United States, it is quite usual to specify that the wetness is not to exceed 0·25 per cent. with the boiler solids at 425 p.p.m. of chloride or 850 p.p.m. of total solids. However, for plants operating at 1,200 p.s.i. or higher, it is becoming increasingly common to specify the solid content of the steam not to exceed one part per million which is equivalent to 0·1 per cent. wetness when the total boiler solids are 1,000 p.p.m.

It is considered that this type of specification has much to recommend it, and advancing steam pressures will surely necessitate its adoption if the turbines are to be kept free from objectionable deposits.

Acknowledgments.

The author wishes to thank the Engineer-in-Chief of the Fleet, Vice-Admiral (E) D. C. Ford, C.B., for permission to use and publish extracts from the records of his Department. The views expressed are those held by the author and they must not be construed as representing those of the Admiralty.

The author also wishes to thank Messrs. Babcock & Wilcox, Ltd., Messrs. Foster Wheeler, Ltd., International Combustion Ltd., The La Mont Steam Generator Co., and Messrs. John Thompson (Wolverhampton) Ltd. for their co-operation and permission to utilize some of their designs.

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Discussion.

Mr. W. Sampson (Vice-Chairman of Council), opening the discussion, said that the paper was long overdue because previously published information on the subject of dryness of steam and priming in marine boilers had not presented the theory and mechanics of priming and carryover in its direct application to marine boilers.

The author opened his paper with the remark: "Why bother about priming?" and then went on to give the reason for bothering. It was really odd that, in view of the application of good theory to most engineering problems, the subject had received so little attention by the great majority of engineers.

When reciprocating engines were the main prime movers, it was perhaps natural to consider that as the slotted dry pipe helped greatly in ensuring against water hammer, leaky joints, piston rod and gland packing troubles, nothing further was needed, yet there had been many horrible examples of smoke-tube superheater failures which the so-called dry-pipe failed to prevent. It was gratifying to hear the author state that it was better to ensure that the steam was dry when leaving the surface rather than to attempt to separate out.

Designers and engineers concerned mainly with moderately-rated Merchant Service boilers would note that the tables in the paper referred to Naval boilers, but they would want to know how high a steaming rate could be reached without any need for mechanical devices in the steam drum, because simplicity and free access to the drum were very desirable.

A matter which called for further experiments leading to exact knowledge was the effect of the permissible steam release rates on the drum size. The trend to-day was towards higher pressures, and the designer had to choose between a large diameter and consequently thick drum with no mechanical devices in the drum to ensure dry steam, or to take full advantage of proven mechanical aids, making possible an appreciable reduction in the drum size with thinner scantlings. There were already pressures of 650lb., using drums 4in. thick, and the thickness of the drum was, for the higher pressures, one of the practical limitations governing the diameter.

Also, the whole trend was for shorter boilers with higher combustion rates following on the introduction of water walls, and those trends were so worth while in their effect that in the boilers of merchant ships all means to ensure dry steam and absence of carryover had to be given consideration to enable the smallest size drums to be used.

It might be as well if all marine boiler specifications included requirements in respect of permissible wetness ratios. With the modern turbine and watertube boiler, arrangements having a closed feed system and means of ensuring practically dry steam at all loads were certainly worth while, but simplicity of internal fittings, ready access to tube ends for examination and cleaning, were points which had to be kept in the forefront.

Eng. Rear-Admiral S. R. Dight, C.B.E. (Member of Council), whose remarks in his absence due to illness were read by the Secretary, said that the author had referred to him (Admiral Dight) in the paper and to wartime troubles with the circulation augmentor which he had invented and developed as the result of investigations into the circulation in boilers some years ago. He also referred to his (Admiral Dight's) paper on boilers to the Institution of Naval Architects in 1936. He did not know the author, who had never in any way been associated with his work in the Royal Navy, and from the author's incorrect statements regarding the augmentor and his lack of reference to the three other papers which he (Admiral Dight) had contributed on the subject of boilers, it appeared that he had not made himself fully acquainted with his subject.

The earlier papers referred to were:—

(*a*) His (Admiral Dight's) contribution to the discussion on Sir Harold Yarrow's paper on boilers at this Institute in 1932.

(*b*) His paper to the Institution of Naval Architects in 1933.

(*c*) His paper to this Institute in 1935.

He would therefore endeavour to fill in the background in order to put the subject on a proper basis as far as oil-fired Naval watertube boilers were concerned, and he hoped they would not find him too discursive or reminiscent.

The boiler developments in H.M. Navy were initiated early in 1918 by a Wartime Admiralty Engineering Advisory Committee under the chairmanship of Eng. Vice-Admiral Sir George Goodwin, so well-known to members as President of this Institute some years ago. Mr. Sterry B. Freeman, one of our Vice-Presidents, was a member of the committee, to which he (Admiral Dight), after active service abroad, was attached as liaison officer. This committee was formed to advise on the engineering troubles which were being experienced under war conditions. Among the items investigated were the old enemy, condenser tube corrosion, the limited radius of action of ships due to high fuel consumption, and the rapid burning out of fire-row boiler tubes, especially in destroyers.

Until that time, ships' boilers were designed by the well-known boiler manufacturers, who supplied the boilers to the Navy. One way to improve the fuel economy, and thereby increase the radius of action, would have been to have superheaters which would give a high degree of superheat at cruising powers, *i.e.* at low boiler outputs. The representative marine boiler manufacturers were interviewed by the committee, and all agreed that such a requirement was quite impossible to meet, as such superheaters would be overheated and burnt out due to the higher temperatures at high outputs. This was definitely the case with superheater boilers as designed at that time.

Being very young and enthusiastic, he (Admiral Dight) decided to attempt to achieve the impossible, and thanks to the encouragement of Eng. Vice-Admiral Sir George Goodwin, and the friendly advice and help of Mr. Sterry B. Freeman, he succeeded in his endeavours, and an experimental superheater was fitted to a boiler under his direction at Messrs. Babcock & Wilcox Ltd.'s works at Renfrew, where he carried out tests with it. This gave the desired result, *i.e.* a high superheat at both low and high powers. The boiler was obtained for him by Mr. R. M. Gillies, a Vice-President of this Institute. Particulars of these developments were given to this Institute in 1932, and to the Institution of Naval Architects in 1933.

Since 1919, nearly all the boilers in H.M. Navy had been made to Admiralty designs based on his (Admiral Dight's) original invention and design, and were known as Admiralty superheater boilers.

In order to investigate the overheating of boiler tubes, he decided first to investigate the circulation in the boiler tubes of a Naval watertube boiler. For this purpose he devised a small pitot-tube apparatus for inserting into the lower end of the fire-row tubes, in order to get an indication as to what was happening, and when the circulation broke down. This apparatus was made to his requirements by a member of this Institute, Mr. Richard Allen of Bedford, who was interested and enthusiastic. Mr. Allen not only calibrated the pitot tube, but gave him the apparatus, as he had no Admiralty authority to pay for it. The apparatus was sent to Haslar in 1919 where, after two tests under unsatisfactory conditions, the work was abandoned.

He studied and worked on boiler developments when at the Admiralty, by observation and tests when serving afloat, and when on trials of new ships. While serving afloat as Engineer Commander in H.M.S. *Dragon* in 1923, and later in H.M.S. *Furious* in 1928, he developed and introduced new and original methods of operating the boilers and machinery. These resulted in a reduction in fuel consumption of more than 25 per cent., and were the subject of special reports from these ships to the Admiralty.

He was finally appointed in charge of the Fuel Experimental Station at Haslar where, in addition to the normal oil-testing and burner-testing work, he invented and developed, in 1930, the efficient and smokeless oil-burning system at present in use in nearly all H.M. ships. This system operated with only ten per cent. more air than was theoretically necessary for combustion, and showed an overall economy of about ten per cent. over the previous system, besides being smokeless. These burners were designed and tested up to outputs of 4,000lb. per burner per hour, instead of being limited to 900lb. per burner per hour as in the earlier system.

In an old storeroom at Haslar he discovered the parts of his original pitot-tube apparatus, which had been sent there for test in 1919. After overhaul and repair he fitted it to boiler tubes whenever the boilers were steaming for fuel tests. Over a period of years he collected a large amount of data regarding circulation, which was later made public in his papers. This data formed a basis for the modern theories on this subject.

These results enabled him in 1932 to invent and develop the circulation augmentor, in order to improve the circulation in the fire-row tubes. The further inventions and developments, including steam drying, feed arrangements, feed regulators, etc. published in his paper to the Institution of Naval Architects in 1936, and his invention of oil fog for screening purposes, were produced by him at that time.

In order to prove the value of the circulation augmentor and to convince the Admiralty of its usefulness, he increased the rate of oil burning in a boiler at Haslar until several tubes became overheated. This took place at only 15 per cent. above the nominal full output. The boiler was of the design used in destroyers at the end of the 1914-1918 war, and his test indicated that the overheating then experienced was due to this small margin of safety. He then fitted an augmentor to the boiler and increased the rate of oil burning up to 45 per cent. above nominal full output, the limit of his air supply. The boiler tubes showed no signs of overheating, indicating that the margin of safety had been greatly increased and his 1918 problem solved at last.

Further tests were afterwards carried out at the works of Messrs. John Brown & Co., Ltd., Clydebank, with one of the superheater boilers for a new destroyer, H.M.S. *Ilex,* which was fitted with circulation augmentors. The fans for three boilers were fitted for air supply to the boiler. The rate of oil burning was increased 10 per cent. at a time, above the normal maximum rate, until eventually a maximum rate of 90 percent. above normal was attained, the limit of the air supply. To do this the rates of combustion and evaporation were far beyond anything previously achieved, and the fire-row tubes showed no signs of overheating. Naturally, at these excessive rates there was a gradual falling off in superheat, but at normal outputs the designed superheat was obtained in all boilers of that design fitted with the augmentor during his period of service at Haslar.

This great margin of safety enabled them to get much more power out of the boilers and, with all the other developments already mentioned, made it possible to reduce the number of boilers in ships. This gave a saving in space, weight and manpower. The aircraft carrier H.M.S. *Furious* was fitted with 18 boilers, while more modern aircraft carriers of considerably greater horse-power had only six boilers. With only two boilers in a destroyer instead of three, only one funnel was required instead of two, giving greater space for armament. A considerable reduction in stokehold staff also resulted, and more weight and space was available for other purposes. The K-Class 5th Flotilla, commanded by Lord Louis Mountbatten in H.M.S. *Kelly* in this last war, were of the two-boiler, one-funnel type. Lord Louis Mountbatten was very enthusiastic about the performance of these boilers when he met him on the trials of the destroyers, and he visited him (Admiral Dight) at Haslar on several occasions to watch demonstrations of the technique and ease of handling of the boilers, worked up to high outputs. The rapidity with which full output could safely be developed enabled the flotilla to be accelerated from cruising power to maximum power in only two minutes. This technique of quick acceleration of ships was originally developed by him (Admiral Dight) when serving in H.M.S. *Furious*. There it was of the greatest importance to attain the high ship speed necessary for landing-on or flying-off aircraft, as quickly as possible. This required a very rapid increase in the output of the boilers. Ordinarily it was essential to increase the output of a boiler very slowly, in order to avoid priming and carryover, which would result in loss of superheat and probable damage to the machinery. By a careful study of the conditions which caused this priming, he was able to develop a system of boiler control and operation which made it possible to increase the output quickly, without fear of priming or carryover; and to increase the output of the boilers at a very fast rate, which was certainly quite impossible with ordinary methods. No smoke was produced at any time during these changes, or when steaming steadily.

In H.M.S. *Furious* it became the normal routine to go from 10 knots to 28 knots in less than four minutes. This quick acceleration used to cause consternation in any attendant destroyer untrained in these methods, as it would be left miles behind, struggling to keep the ship in sight and get back into station again. On one occasion when the ship was steaming at only six knots in the Mediterranean, the pilot of a damaged aircraft signalled his wish to make an emergency landing. The ship's speed was increased from six to 28 knots, the ship turned 180° into the wind, the aircraft safely landed-on, and the ship's speed eased to 10 knots. The whole of this evolution was completed in eleven minutes.

He instructed all engineer officers visiting Haslar in these operational methods, which were of great military value in H.M. ships during the war, as these rapid changes in speed often assisted our ships to outmanœuvre the enemy ships.

To conclude, he would like to explain that after he left this development work in 1939, he was appointed to work under the Vice-Chief of Naval Staff on more military duties in connection with the various uses of fuel oil in warfare, particularly the development and use of oil fog for the protection of vital targets against air attack. He also carried out the technical work in the campaign to reduce funnel smoke from merchant ships. In this he was greatly assisted by the close co-operation of Mr. W. S. Burn, Mr. J. Calderwood, Mr. H. S. Humphreys, Mr. H. J. Wheadon, and other members of this Institute.

He hoped that he had now made clear the use and value of the circulation augmentor, and shown that, during his time, the dryness of steam in Naval boilers was well looked after. It would of course be impossible to obtain the designed superheat in boilers, as was done in every case in his time, unless the steam was quite dry.

None of the augmentors for these wartime high-output boilers, in which these troubles had arisen, was designed by him.

He was reminded of the old story about the leadsman who, when reporting soundings in the usual monotonous chant, so misled his captain by not changing the words as the soundings became less, that the ship ran aground. On being interrogated, the leadsman said he was new to the job; he knew the tune, but not the words!

That there must be some basis of truth in this story was shown in the case of the augmentors, as without learning the words, *i.e.* the method of designing them, the augmentors had only been made to look like his design. The statement that the sloping sides were necessary for clearance for the E-row tubes was incorrect. The dimension which really mattered was the area at the top of the augmentor and its proportion to the total area of the tubes discharging into it.

In the boilers produced in his time, the fire-row tubes joined the drum tube-plate at an acute angle, and the space between the tube rows was therefore very great. The area of the augmentor at the tube-plate was therefore greatly in excess of the area of the tubes. In this case the width of the outlet was reduced, and the sides sloped inwards to give the correct area for discharge. In the more modern boilers, a greater amount of bending of tubes was accepted, and the tubes entered the tube-plate more nearly at right-angles and were packed close together. The base of the augmentor was therefore much narrower than in the original designs, and to get the correct discharge area and velocity at the mouth of the augmentor, the width at the top might even have to be greater than the width at the base, and the sides sloped outwards, depending on the closeness of the tubes. The increase in the maximum rate of output of these boilers also necessitated a greater area for discharge in order to avoid carryover and loss of superheat.

Only in one special case would the sides be parallel, if the augmentor was correctly designed.

It was therefore strongly recommended that the somewhat specious remedy of making the sides parallel in all cases be abandoned, and the augmentors correctly designed for each boiler.

He wished again to point out that in the case of the high-output boilers in which these troubles had arisen, the augmentors were not designed by him. He had never before heard of these difficulties, and was entirely at a loss to understand this publication of them, coupled with his name, without any previous reference to him.

Unfortunately, it was so often the lot of inventors and pioneers to get no credit or thanks for their work, but to be saddled publicly with the blame when others misused their inventions and discoveries and got into trouble.

Mr. R. F. Davis (Visitor) said that he had a comment to make on the constant of 12·35 in equation (*2*) on page 59, which was based on an assumed drag coefficient for a spherical drop of 0·858. Actually the drag coefficient depended on the Reynolds number, and from data published by *Lapple and Shepherd in their calculation of spherical particle trajectories it would appear that a coefficient of 0·40 would more nearly correspond to the conditions in a boiler drum. That change would increase the constant in equation (*2*) to 18, but it was possible that a liquid drop suffered a certain amount of flattening in its direction of motion and its effective drag coefficient might, therefore, be greater than that of a true sphere and nearer the value originally assumed.

With regard to the statement on page 64 to the effect that the particles in a steam separator or dryer obeyed Stokes' law, the speaker had concluded, after investigation, that the majority of the drops produced by the effervescence of the steam bubbles were of the order of one-third mm. in diameter and, therefore, well above the limiting size of particles which would conform with the streamline motion demanded by Stokes' law, but rather their motion would be turbulent and follow Newton's law of resistance as expressed by equation (*2*). There was no reason to suppose that the drops, when they reached the separator, would be substantially smaller than when originally projected from the water surface. That did not, however, detract in any way from the author's general conclusions which followed in the subsequent paragraph.

The author did well in drawing attention to the difficulties of sampling and measuring wetness in steam. The throttling calorimeter could still give astonishing results at high pressures, even when using steam tables within the limits set by the Steam Tables Conference. The electrical conductivity method was accurate when the technique had been mastered.

With regard to the advantages of different types of internal fittings, he had a very open mind on the subject. As in a marine boiler, the method adopted for a land boiler depended largely on the geometry of the boiler design. Where all the steam release tubes could be accommodated well below the water level—as they could in many modern large high-pressure boilers of the radiant type without convection banks—it was the practice now to spread the incoming steam as evenly as possible over the entire water surface by submerged deflecting baffles, so as to give as low a surface steam release rate as possible. Where the risers had come above the water level the steam had either been led below to discharge through a submerged perforated baffle plate, or to discharge downwards above the water level through reversing hoods, similar to the design shown in Figs. 15, 16 and 17. The sections illustrated were actually for a small test boiler of marine type, and from which it was hoped to obtain some figures when it steamed in a few weeks' time.

Generally speaking, the present tendency was to install the absolute minimum of internal fittings. Experience with so-called dryers had been that due to the consequent internal pressure drop to ensure sufficient velocity for separation, some were liable at high ratings to become effective wetters by sucking water up the drain leg.

Another important practical consideration was to take the steam from the drum as uniformly as possible and from the highest point. In land boilers with drums of the order of 30ft. long, the practice now was to connect the individual superheater elements directly to the drum all along its length; or if that could not be done, to fit an internal perforated collecting pipe to give a uniform rate of take-off. The theory underlying the design of such a pipe would

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*Lapple and Shepherd, 1940, "Calculation of Particle Trajectories", *Industrial and Engineering Chemistry*, Vol. 32, No. 5, p. 605.

shortly be published †elsewhere, so reference would not be made to it except, perhaps, to state that recent tests had shown that a pipe designed on the basis of that theory did provide substantially uniform collection.

Mr. R. E. Zoller (Visitor) said that the author had touched on practically every aspect of the problem, which was to deliver steam to the superheater without any trace of liquid or solid, and he had very little to add. In the discussion on Mr. Davis's paper he had disagreed with many of his theories, most of all the factor of safety of four that Commander Baker had shown to be unnecessary. He thought that the first part of the paper gave the impression that wetness values of 1-5 per cent. were acceptable, and it was with relief that he read the recommendations at the end. The first, to limit the moisture to $\frac{1}{4}$ per cent., was well within the present capabilities, but a value of $\frac{1}{10}$ per cent. at 1,200lb. pressure would be difficult to guarantee with a ship at sea.

The Germans had many naval boilers operating at 1,000lb. per sq. in., and they seemed satisfied with moistures of 1 to $1\frac{1}{2}$ per cent., but their destroyers had several superheater-tube failures due to priming with release rates of 1,600 to 2,800lb. per sq. ft. G.P. and volume ratings of 550 to 780ft.^{3}/hr. ft.^{3}. Neither of these values was high by comparison. The *Scharnhorst* and *Gneisenau* operating at 800lb. per sq. in. had even more trouble with ratings of 1,300 and 4,200 respectively.

When considering American naval practice, it was possible only to compare the actual moisture measurements because, as pointed out in the paper, drum liberations did not apply when steam cyclones were fitted. Of the fighting ships now in service with the American Fleet, practically all had a system of drum internals illustrated in Fig. 22.

Boiler	Babcock controlled superheat		Two-drum boiler With baffles	Two-drum boiler With cyclones
Load	Full power	60% overload	Full power	23% overload
Output, lb/hr. ...	160,000	260,000	65,000	80,000
Wetness, %... ...	Nil	0·25	More than 0·25	Less than 0·1
Drum pressure, lb. per sq.in. ...	600	600	400	400
Drum diameter, ins.	50	50	42	42
Gross water plane, sq.ft.	32·7	32·7	20·8	20·4
Mean release rate, lb. per sq.ft. per hr....	4,900	7,950	3,120	3,920
Volume of steam space, cu.ft. ...	53·4	53·4	34·1	20·1
Volume rating, cu.ft. per cu.ft. per hr....	2,180	3,530	2,120	4,400
Water level... ...	Centre line	Centre line	3 in. below centre line	5 in. above centre line

The above table, which was similar to that on page 62, gave extracts from tests made at an independent testing laboratory. The calculated drum liberations showed the reduction that could be made on drum sizes without moisture carryover, although it was not always possible to reduce the drum as it would be too small to accommodate the tube connections.

The first column in this table referred to a boiler operating at 600lb. per sq. in. No moisture could be measured at full power either by throttling calorimeter or by gravimetric determination. At 60 per cent. overload the cyclones were much overrated, but the moisture did not exceed $\frac{1}{4}$ per cent. More steam cyclones could have been installed if this high overload had been required in service, and there was no doubt that the same drum could have been used for this high liberation with a lower moisture content than $\frac{1}{4}$ per cent.

The last two columns referred to a test made on a small two-drum boiler which was fitted with a system of submerged baffles similar to Fig. 11. After many arrangements had been installed and found ineffective, the results in column 3 were the best recorded with submerged baffles. Later the same boiler was fitted with cyclones and the first test with these was given in column 4.

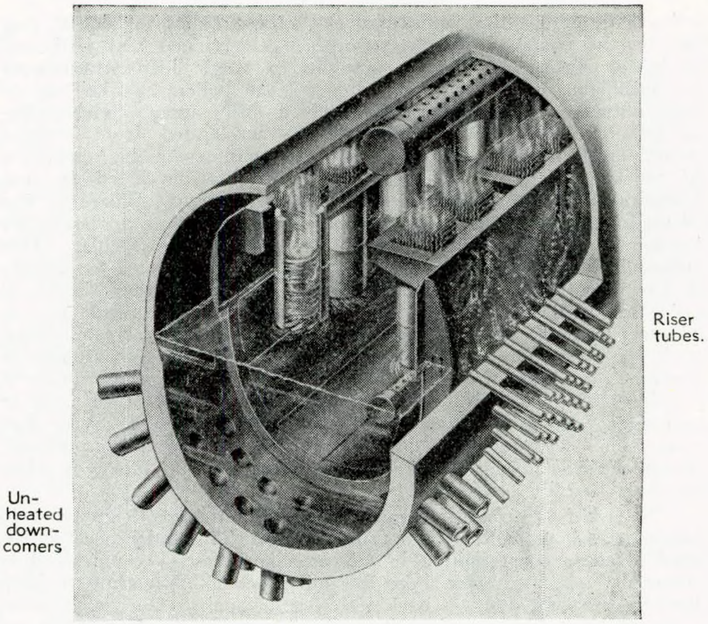

FIG. 22.—*Impression of steam cyclones in a controlled superheat boiler with unheated downcomers.*

There was a great improvement even with a much higher boiler concentration and with the water level 5in. above the drum centre-line. Previously, heavy priming occurred if the water was allowed above a point 3in. below the centre-line.

Referring back to the illustrations, he must apologise for

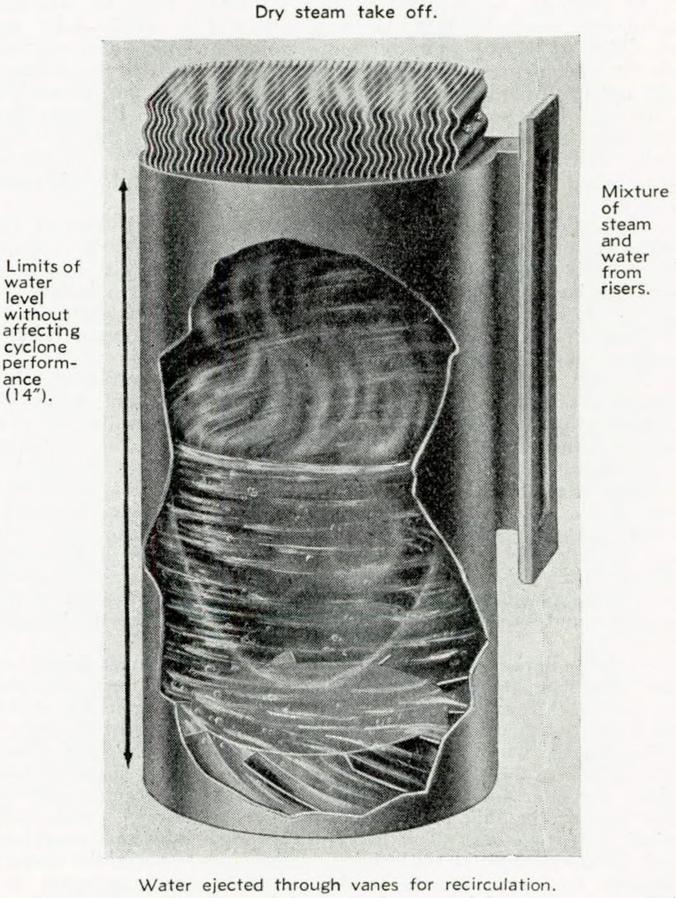

FIG. 23.—*Detail of individual cyclone showing vortex of water.*

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†As a written contribution to the paper "Feed Distribution and Hunting in Marine Boilers", by H. Hillier. *Inst Mech. Engrs.*, Nov. 1946.

duplicating Figs. 13 and 14, but an attempt had been made to illustrate the cyclones in operation. Cyclones were fitted in pairs, held with a single strip and two nuts, so that when inspection was necessary all the internals could be taken down in less than an hour and left in the bottom of the drum.

It might be of interest that the cyclones were primarily designed to improve circulation by eliminating steam bubbles from the water entering the downcomers. This small quantity of steam materially reduced the circulating head. The first boilers to have cyclones had their circulation measured by various methods; the improvement was 10 per cent. Many more designs had been checked by observing the depression in long gauge glasses, and in no case had the improvement been less than 10 per cent. as compared with a boiler having the same downcomers and submerged baffles.

He hoped the above showed that he supported the author's conclusions, and he had only one quibble with the text. On page 57 the author stated that salts crystallized out after evaporation, which was true with the exception of caustic soda. If a drop of water containing caustic soda entered a superheater operating at 300lb. per sq. in., the water evaporated until at 650° F. the drop was reduced to ⅕th water and ⅘th salt. This was quite sticky, so that if a drop became attached to the tube it would collect other salts on the inner surface. Similar drops in contact with superheated steam at 400lb. per sq. in., 750° F., contained about 90 per cent. caustic soda and at 600lb. per sq. in., 850° F., about 95 per cent. This showed that with higher steam temperatures the water was never driven right off, but that the proportion of caustic soda became higher, and this made the solution more sticky. He appreciated that it was possible by correct water conditioning to counteract the effect of the caustic soda causing deposits in the superheater piping and turbines.

Mr. R. L. J. Hayden (Visitor) said the paper represented a very thorough summary and survey of current theory and practice with regard to the control of steam purity.

Quite naturally the emphasis had been on boilers working at Naval ratings where a plain water surface would not usually give the desired steam quality. However, with the majority of mercantile boilers working at lower ratings, a plain water surface would give quite satisfactory steam purity while maintaining ease of access to tube ends for survey.

As an example, his firm had a considerable number of marine two-drum boilers in service with steam drums of 42in. internal diameter. The furnace depth of those boilers was 10ft. and a normal evaporation of 40,000lb. per hour was produced at 470lb. per sq. in. with only vertical surge plates and dry pipes. That corresponded to a rating of 1,140lb. net release area. Steam purity had been quite satisfactory and access to tube ends involved no dismantling of the drum.

In recent shore trials with a controlled superheat Naval boiler as described in the paper, tests were carried out with only three vertical surge plates in the drum which was of 50in. internal diameter. The boiler was working at 400lb. per sq. in. drum pressure, and with those simple internal fittings a ¼ per cent. of moisture was recorded at an evaporation of 93,000lb. per hour with a water level of 3in. in the gauge glass. That corresponded to a rating of 3,700lb. per hour of steam of net release area.

After those tests several arrangements of perforated plates below water level combined with dry pipes and baffles in the space were fitted. The results with all those arrangements showed an improvement over the results with the plain drum. The best arrangement gave ¼ per cent. of moisture at 160,000lb. per hour evaporation with 7in. level in the gauge glass. That corresponded to a rating of 6,400lb. of steam per hour per sq. foot of net release area, nearly double that with a plain drum. These perforated plates were made to hinge back against the walls of the drum and gave fairly easy access to the tube ends.

By the figures given in the paper, higher evaporation could be obtained from that size of drum with cyclone type separators, while still maintaining a purity of ¼ per cent. of moisture. The use of that type of internal fitting would necessitate their removal to obtain access to tube ends, and would probably involve the use of additional downcomers to enable the circulation of the boiler to be maintained.

In the course of the trials mentioned above, confirmation was obtained of the critical steam velocity suggested by Mr. Davis at 400lb. per sq. in. With the best arrangement of perforated plates giving an approximation to an even release rate over the drum area, the wetness of the steam increased rapidly above 210,000lb. That corresponded to an average rising velocity of steam of 2·6ft. per second, which showed close agreement with Davis's results without, as the author stated, the safety factor of four.

The boiler was fitted with two saturated steam pipes, one approximately on the centre of the drum and one towards the front of the drum nearer the burners. The rear saturated pipe always showed the most moisture, while at all except overload ratings the steam in the front pipe was dry.

Various internal baffles were fitted in the top of the steam drum to give an effective offtake of steam at various points along the length of the drum. The results of the trials showed that there was an optimum point for the offtake of steam. If the offtake were taken forward of or in the rear of that optimum point, a worse result was attained. The position of that optimum point was approximately in the position indicated by the author, *i.e.* in the front half of the drum nearest the burners and about a third the length of the drum from the front.

None of the many types of baffle or dry pipe fitted at the top of the drum effectively prevented carryover, and that would seem to suggest, as the author stated, that the main duty of a dry pipe was to break up any large surge of water caused by unusual circumstances such as high water level.

It would be interesting to have the author's opinion on the effect on the steam purity of supplying the feed above the water level, and to know whether in Naval boilers he had experienced any carryover due to the type of spray feed pipe used by the Admiralty.

Undoubtedly the secret of the satisfactory operation of purifiers relying on centrifugal separation of water from steam, whether they be of the Tracy or Vortex type, was adequate height in the drum for drainage. Unless that height was available, the fitting of those devices might result in more moisture in the steam than with a plain steam outlet from the drum. The problem of drainage increased with increasing pressure, and where adequate height was not available in the steam drum, the best solution was to carry the drains to the lower drum. That had been done with success at 600lb. pressure.

The Tracy type of purifier had undoubtedly done good service in the old days as a dirt separator in lower pressure marine boilers.

He disagreed with the author's statement that drain pipes from such purifiers should finish with a U-bend and no drain valve. In the early days of the Tracy purifier the drain pipes were carried straight down below the water level. Open U-bends, as suggested by the author, were also used. Neither of those drain pipes gave entirely satisfactory results. Hinged flap valves were tried, but were unsuccessful because they stuck open. Then a U-bend fitted with a light mushroom-type of non-return valve was developed with a definite improvement. That valve served the purpose of preventing surges of water up the drain pipe in the event of sudden increases in boiler evaporation.

The author had stated that the use of the normal reading with throttling calorimeters was not desirable. If accurate readings of moisture were required, under usual test conditions encountered time was not available as a rule to do otherwise than work to a normal. He had never seen agreement within several degrees between the recorded normal and the calculated temperature using the steam tables suggested by the author.

The normal temperature taken at low load might be higher than the theoretical due to the conduction of heat through the calorimeter flanges, or below the theoretical due to heat losses from lagging. As one degree represented approximately one-sixteenth per cent. moisture, the normal figure should be used as a zero.

Mr. G. A. Plummer (Visitor) said he came not to bury Cæsar but to praise him! He had not come to criticize but if possible to amplify a most valuable and timely paper.

The author had presented in the most workmanlike manner a valuable review of a subject, the importance of which had not been fully appreciated by engineers. If anything, the author had, in his opinion, rather understressed the ill effects of carryover and priming.

A few years ago he (the speaker) had experienced a case of a 30,000-kW. turbo-generator, the output of which was reduced to 20,000-kW. in three weeks even with the overload valves fully opened, entirely as a result of deposits on the turbine blades resulting from gross carryover. He had for many years been interested in such problems and had dealt with the matter in a paper presented to the Institution of Mechanical Engineers on January 18th, 1946.

It was interesting to note from the table given on page 62 of the paper that the S.G.B. La Mont boilers, even with the old-type of internal baffles, showed no carryover at maximum output. Fig. 24 showed an early arrangement of internal baffles in La Mont boilers.

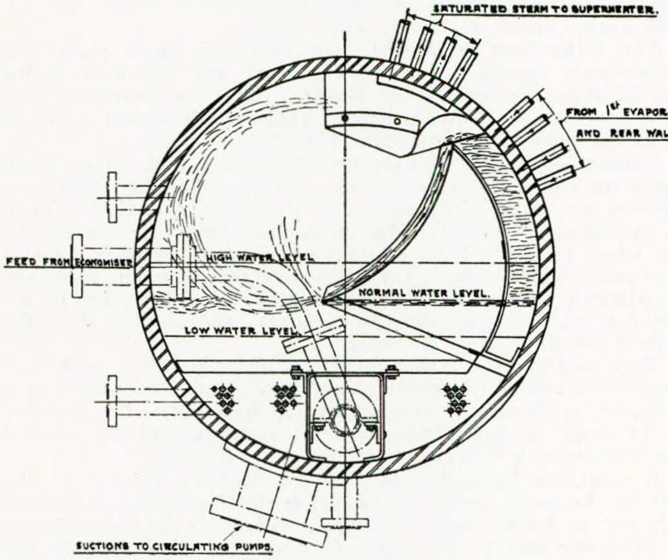

FIG. 24.—*Early arrangement of internal baffles in drum.*

Later on, the fact that they had been dealing with forced-circulation boilers enabled them to have the boiler filled with water to within a few inches of the manhole, have the manhole open and the boiler circulating pumps started. It was thus possible to simulate actual conditions to some extent which could be amplified by injecting compressed air into the circulating circuit. He had actually entered boiler drums when working under those conditions, and was able to gain first-hand if somewhat painful experience as to the behaviour of internal baffles and the directional effects of flow.

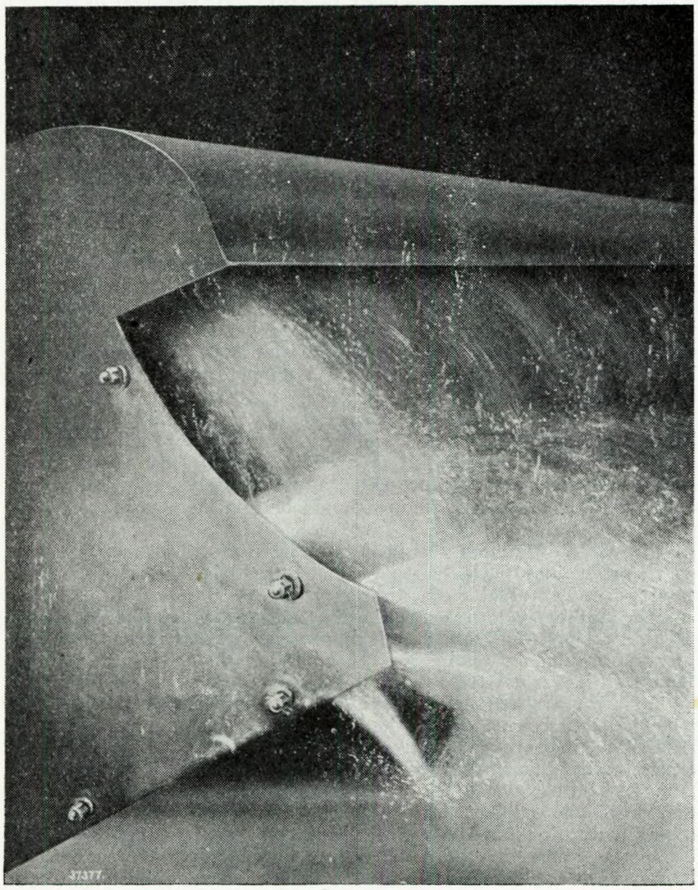

FIG. 25.

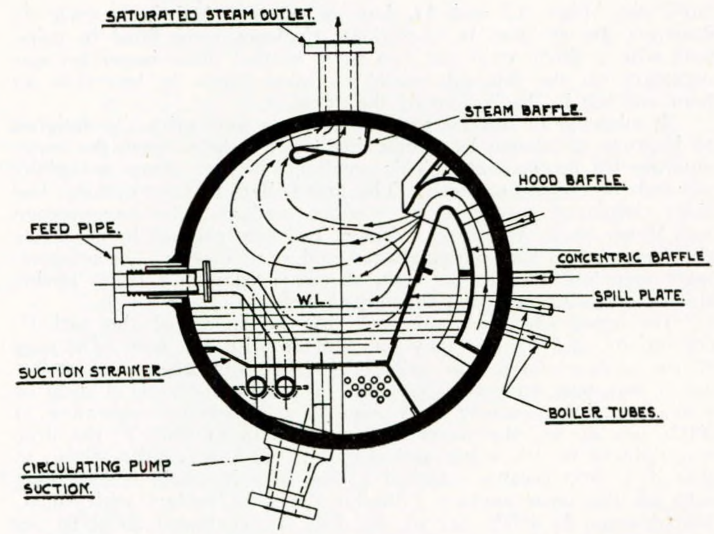

FIG. 26.—*Modern arrangement of La Mont internal drum fittings.*

One of the first and most useful lessons he had learned was the amount of splashing and spray that could be caused by inadequate attention being paid to the tightness of joints and the presence of undesirable projections. Fig. 25 illustrated this.

In his opinion, many internal baffle arrangements had been carefully thought out and installed in good faith by designers, but had been rendered negative by careless or inadequate fitting, and the importance of attention to minor details such as the tight fitting of baffle plates, the avoidance of projections, etc. could not be too highly stressed. One of the next important lessons learned by actual contact with the internal workings of the drum was the importance of directional effects of flow.

On page 58 the author referred to the velocity of projection of droplets. In the case of the La Mont baffles the initial upward

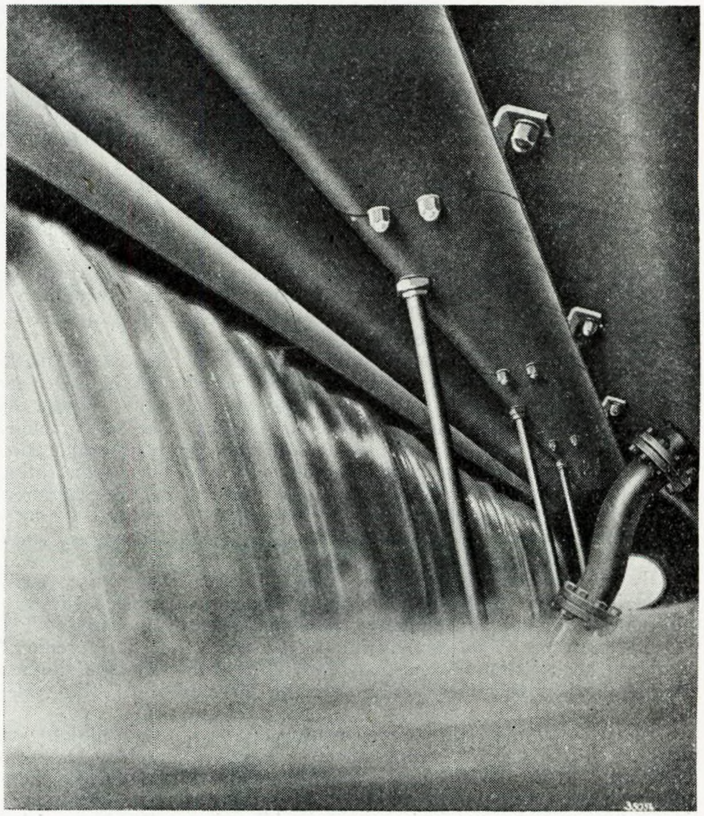

FIG. 27.

direction of the steam was reversed to a downward direction, thus entirely combating the question of droplet projection.

It had been found as a result of investigations conducted inside boiler drums that the more steeply the flowing water could be directed downwards into the water surface, the less was the disturbance of the water level. Fig. 26 illustrated the more modern type of internal baffles now adopted, while Fig. 27 showed the even flow obtainable from such baffles.

The purity of the steam resulting from such an arrangement and determined by the electrolytic conductivity method was to be observed in Fig. 28, which was part of a record taken from a high-pressure La Mont boiler operating at 1,400lb. per sq. in. pressure.

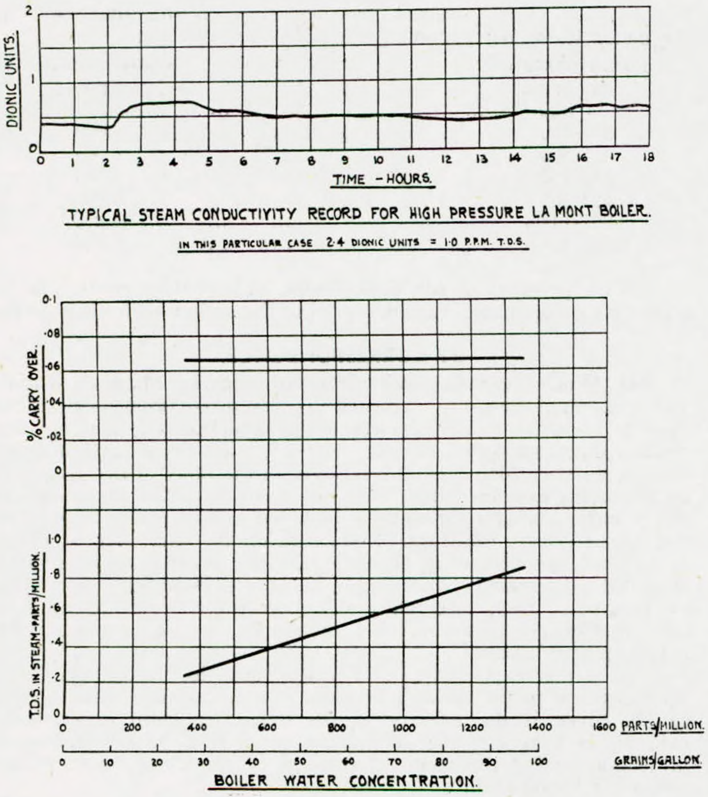

FIG. 28.—*Percentage carryover (moisture) and equivalent total dissolved solids in steam for high-pressure La Mont boiler.*

The general principles of the internal baffles adopted for La Mont boilers had now been applied to natural-circulation boilers. Figs. 29 and 30 illustrated the latest types of land boiler developed and the internal baffles for such boilers.

It would be seen that the rising steam and water was directed into the steam drum above the water level. The direction of the steam and water mixture was turned downwards on entry into the drum. The steam did not pass through the water level.

With boilers equipped with similar internal baffles, it was felt that the more true criteria for carryover was the steam release per cubic foot of steam space per hour.

It would appear that the arrangement of Figs. 6 and 7 could be materially improved in regard to Admiralty three-drum boilers, and he suggested that it would possibly be worth while giving consideration to the adoption of a baffle system somewhat similar to Fig. 8 of the paper, but of a double form, that was, with a single central vertical baffle, extended on each side of its upper extremity to form a double hood baffle, deflecting the rising steam and water downwards on to steeply-inclined spiller plates, forming the sides of the augmentor.

Mr. R. G. C. Richardson (Member) said that the paper was of special interest to marine engineers, as watertube boilers were finding increasing favour in the Merchant Service and also as pressures and ratings were rising and the boiler duties were becoming more severe.

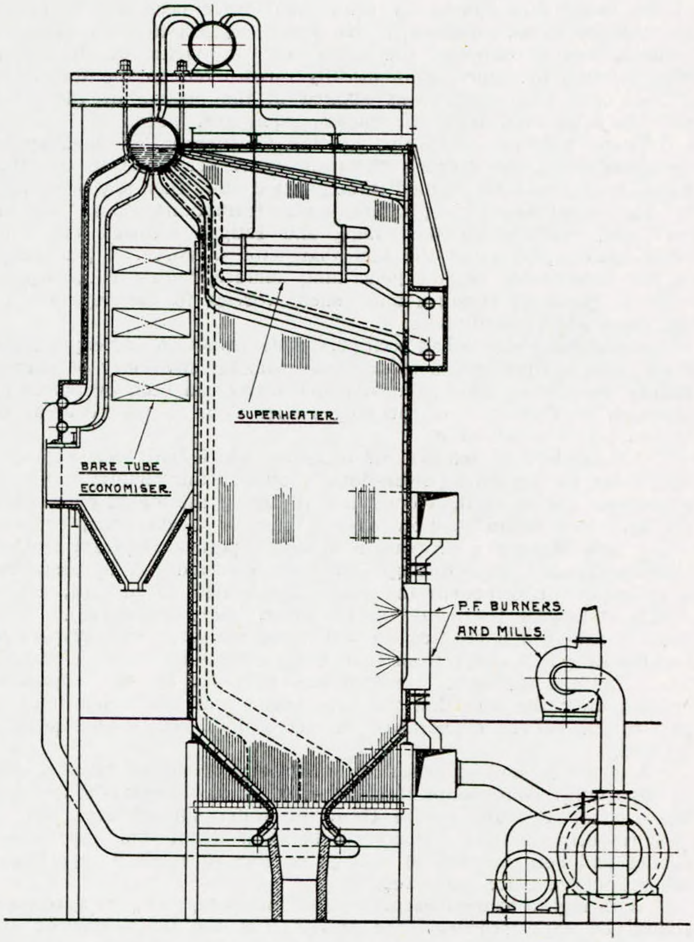

FIG. 29.—*"Etaflo" boiler.*

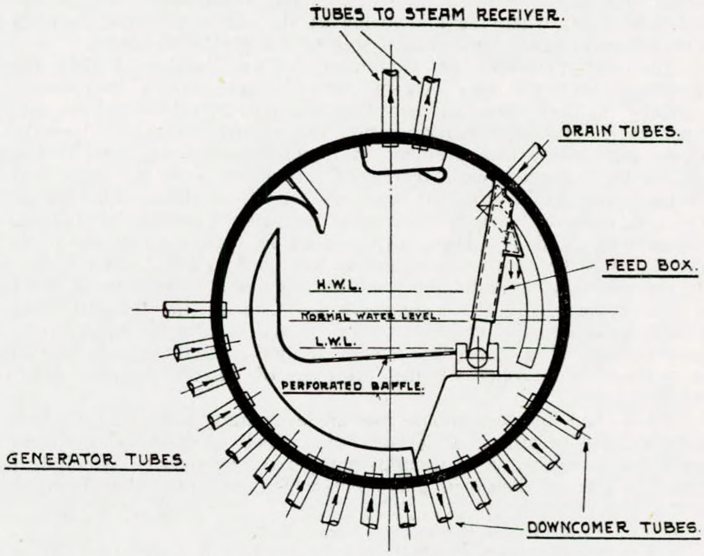

FIG. 30.—*Internal baffles of "Etaflo" boiler.*

With regard to the author's remarks on the effect of the deposition of the salts in steam pipes, no doubt whilst this was true of watertube boilers and turbine installations, it might be of interest to remark that serious corrosion troubles had occurred in Scotch boiler installations, affecting specially the steam inlet pipe to the saturated header where it passed through the air heater. The speaker had known of cases where these pipes had perforated in six months' service. He would question, therefore, the author's statement that "salts are deposited at a bend where a change of direction of the steam flow causes the centrifugal force necessary to throw the salt out to the tube wall". He would suggest that the moisture globules which contained the salts were, by virtue of the steam flow through the pipes, automatically thrown out to the walls, but it was only where heat was applied to the outside of the pipes that the salts were dried out and corrosion took place.

There was no doubt that so far as superheater installations were concerned, the author's statements were very true, as unfortunately the superheater seemed to be affected more than any other part of the installation by priming scale formations, local internal corrosion, cracking of the tubing and fatigue failures, etc., this being quite apart from the fact that with carryover a percentage of the superheater became generating surface, with the consequent loss of steam temperature and added worries to the suppliers of the superheater installation.

All of these effects had been personally witnessed and experienced from time to time and in most cases—whether stationary or marine boilers were being considered—the difficulties had been overcome by attention to the cause of priming rather than to the removal of moisture as a result of it.

One method of removal of moisture which had been exploited with some success on a power-station boiler in this country might be of interest. This method consisted of drying the steam by causing the saturated steam to flow over a nest of steam coils, through which was flowing a proportion of the superheated steam leaving the superheater (flow through the coils was induced by installing a resistance or orifice in the main superheated steam pipe, across which resistance the coils of the dryer were connected). This method provided a surface on which the moisture was evaporated and the salts deposited; from time to time the salts could be washed free from the surfaces. Nevertheless, provision of such apparatus did not alter the fact that the superheater was still being used as part of the boiler's evaporative surface and no regain of superheat accrued.

Experience had shown that uniformity of steam take-off was as important a contribution to clean steam as was attention to uniform and controlled steam release from the water surface area and, in this respect, multiple connections between drum and superheater header had been adopted in a large number of modern superheater designs where space permitted.

With regard to the measurement of moisture, complete agreement should be expressed with the author that the limitations of the use of the throttling calorimeter precluded this instrument from accurate and absolute determinations. It was, however, a useful instrument for indicating the trend of "priming characteristics" of a boiler. The disadvantage lay in the translation of the readings obtained from the calorimeter in terms of the steam tables rather than in the measurement of the temperature at calorimeter discharge which could be accurately made. To the practical engineer it could be considered a fallacy, as there were such wide variations in the moisture content at a given pressure calculated from the various steam tables published.

Reference might also be made to the use of a flashing calorimeter[*] for the determination of very high moistures—say 20 per cent. and over, when the knowledge of the steam pressure between two orifices in series bore relationship to the moisture content.

In most problems of carryover, it was suggested that the important criterion was "steam purity" rather than "percentage moisture" (where moisture had been limited to values below, say, 2 per cent). For this determination the author's reference to electrical conductivity measurement of a condensed steam sample was one to be regarded with increasing attention both for land and marine boiler applications—it was an accurate method. The author was not, however, strictly correct in inferring that this method of measurement had not been widely used in this country when he stated this to be a second method widely used in the United States. On the contrary, it had been common practice for land installations in this country for some years now. One of the difficulties in quickly assessing the true carryover of solids from a conductivity measurement of a condensed steam sample was the correction to be applied on account of the presence of dissolved gases (CO_2 and NH_3).

They had in continuous use an apparatus based on designs described by Straub and Nelson,[†] in which a degasifying steam condenser furnished a continuous sample of condensate, which had been freed from dissolved gases but which contained the dissolved solids present in the original sample. A continuous chart recording of the conductivity was arranged for and, in general, the apparatus appeared to be highly satisfactory. The complete apparatus was fabricated from stainless steel, including the sampling pipes and connections to the condenser, thus minimizing metallic contamination of the sample. Such an apparatus could easily be applied to marine practice.

Regarding the author's statement on specifications for wetness, the speaker believed the figure of 0·25 per cent. was that which might have been requested by a particular client, as he understood the American boiler manufacturers' procedure was to give no guarantee of moisture content of steam leaving boiler less than 0·5 per cent. Regarding solids, no guarantee of purity better than 1 p.p.m. was given, and this was dependent on the total solids in the boiler water not exceeding the following amounts :—

Drum pressure lb./sq. in.	Total solids p.p.m.
0-300	3,500
301-450	3,000
451-600	2,500
601-750	2,000
751-900	1,500
901-1,000	1,250
1,001-1,500	1,000

On the proposal of **Mr. S. A. Smith, M.Sc.** (Member of Council) a hearty vote of thanks was accorded to the author with acclamation.

BY CORRESPONDENCE.

Mr. Wm. Alexander, Wh. Ex., M.I.Mech.E., M.I.N.A. wrote: The maximum height H reached by drops corresponding to the velocity of rising steam, determined by equation (*1*), and the two co-related sets of curves of Figs. 1 and 2, taken from Davis's paper, could not be considered reliable. Davis, in the reply to the discussion on his paper, explained that "The curves of Fig. 22 (*represented by Fig. 1 in the author's paper*) must be taken as illustrating the qualitative aspect of the influence of pressure on the carryover of drops, rather than as representing absolute velocities, because absolute values depended on constants which could be only satisfactorily determined by research. Such research required very elaborate apparatus to take photographs at a rate of a thousand a second or more inside a high pressure vessel".

He further explained that "The only term in the formula (*19*)—corresponding to the author's equation (*1*)—to which a *definite value* can be given is the velocity of the steam c. Until experimental evidence is available, the determination of both p the velocity of projection, and q the terminal velocity of the drops, must remain somewhat hypothetical".

In any case, the curves referred to were based on (*a*) the assumption that the resistance to motion of a water drop through steam was proportional to the square of the relative velocity, (*b*) the coefficient in equation (*2*) had the value 12·35, and (*c*) the drops were of one size. Whereas, none of these assumptions was justified.

(*a*) Only the larger drops were subject to the velocity squared law (Newton's), and the smaller to the law in which resistance varied as the first power of velocity (Stokes'), or to an intermediate law of resistance.

The full curve shown in Fig. 31, calculated by the writer from results of modern research, showed approximately the relationship between the size and limit relative speed of water drops in steam at 440 p.p.s.i.a., the force being gravity. Above the point A on the curve Newton's law applied; between A and B a combination of Newton's and Stokes' law obtained. Dotted curves for drops of fractional specific gravities were also shown by way of comparison and possible interest.

Davis had stated (see *Journal, Inst. Mech. Engrs.*, Vol. 144, No. 5, p. 207) that "—when floating bubbles burst, drops of liquid are ejected under certain conditions, depending on the size of the bubbles producing them, some are projected to a considerable height". Indeed, there was much evidence that a great range of drop sizes could result from ebullition. Also, splashing and collision could produce drops of many sizes. In effervescence—say of soda water—drops depositing on a bright blade, or a spoon, held above the liquid, varied much in height reached and size, which could be at least as small as 0·2 mm. or 200 microns.

In high-pressure boilers the drops were generally smaller than from such effervescence, because of the lower surface tension at higher temperature. From Fig. 31, no drop below 550 microns was subject to resistance varying as the square of relative speed.

(*b*) the coefficient 12·35 in equation (*2*) was too low for the

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[*] "The Fluid Flow through Two Orifices in Series" by M. C. Stuart and D. R. Yarnall, *Mechanical Engineering*, August, 1936.

[†] "A New Degasifying Steam Condenser for Use in Conductivity Determinations" by F. G. Straub and E. E. Nelson, *Transactions A.S.M.E.*, October, 1941.

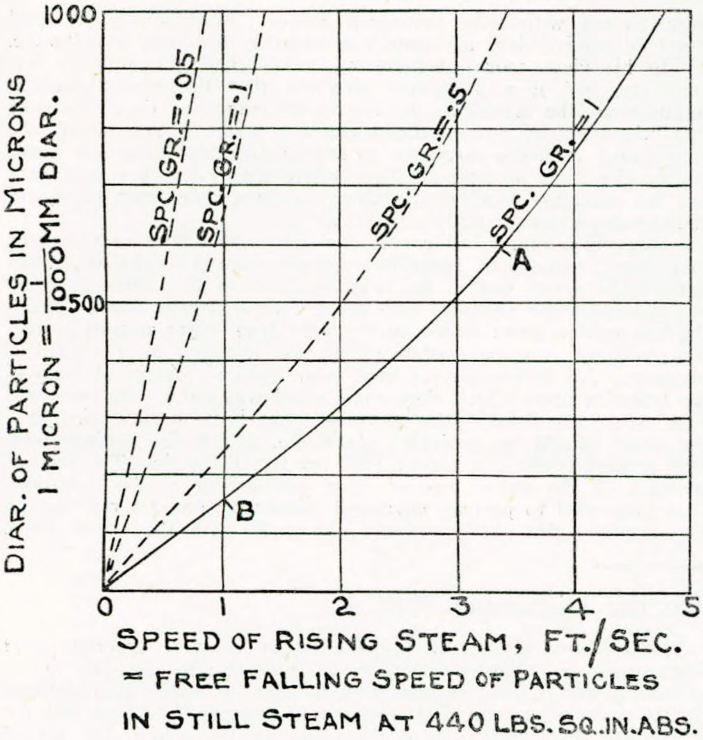

FIG. 31.

velocity squared, or Newton's, law of resistance. The value 17·3 was now generally accepted, based on a drag coefficient of 0·44 instead of 0·858 employed by Davis; see *Modern Developments in Fluid Dynamics,* by S. Goldstein, Clarendon Press, Oxford, and other publications.

(*c*) The three curves in Fig. 1 that turned up vertically at corresponding speeds about 0·88, 1·85 and 3·06 f.s., applied only to one size of drop at these speeds for any of the three respective pressures represented, and were independent of any initial velocity of the drop. The speeds were simply the limit speeds of the drop due to gravity in still steam.

Thus, it was quite unnecessary to derive a formula for the maximum height reached by a drop, because when the steam rose just faster than the limit speeds, the maximum height became intermediate, and the drops must then be carried away unless caught by baffles or dryers. All that was required apparently, for various sizes of drops, was a curve such as was shown in Fig. 31. The curve indicated clearly what drops were carried away and what fell back into the boiler water, at various speeds of steam release at a pressure of 440lb. per sq. in. abs.

In view of the above and because of the roughly qualitative theoretical determination of carryover described by the paper, the stated near agreement of the result of the five shore trials to the Davis results could only have been due to remarkable coincidence. It would have been interesting and useful, in connection with the curves of Fig. 5, if the drum internal fittings for steam drying (if any) had been shown or described. Perhaps this could yet be done.

The complete absence of water in steam from boilers fitted with the Dight augmentor, up to full designed overload, was a fine achievement, and surely suggested a greatly extended adoption of this component for boilers of design other than Admiralty type, if such adaptation were feasible.

The table of particulars of various boilers was not referred to in the text of the paper. It would have been of greater value if additional important factors affecting steam dryness had been tabulated or stated—for instance (*1*) water level, because for one of the tabulated boilers steam dryness was said to have been adversely influenced by low water level, whereas in other boilers dryness suffered with high level; (*2*) the respective methods of sampling and measuring the wetness of steam, types of calorimeter, etc. The writer had found it hard to believe that, when an augmentor or any other device was used, steam could rise among water drops without some of the smaller ones, at least, being carried away. It might be that the perfect dryness for the tabulated Admiralty boiler was apparent only due to some error in the dryness tests or fault in the calorimeter. Obtaining absolutely dry steam from a highly-rated boiler was indeed so rare that most engineers would welcome a fuller statement of the means and principles by which it was obtained; and also as to whether the augmentor was applicable to boilers other than the Admiralty three-drum type and, if so, whether equal steam dryness could be expected or obtained. If not obtainable, then what precisely were the features in the combination of augmentor and Admiralty boiler that gave the remarkable result of perfectly dry steam?

On the design of dryers, the author had curiously remarked that "The basic error of all 'dryers' is that it is fundamentally wrong to start what you cannot stop". This could not possibly be construed to mean, as he had said it did, what was expressed in other words in his next sentence, for a dryer did not start wetting the steam; it was ebullition which did that. His quoted sentence had given the impression that he was definitely against the use of dryers.

The statement (page 64) "The cross velocity that can be attained by a drop is limited by the resistance of the steam to its flow" was hardly correct. Possibly what was intended instead of the last three words was "on the drop" or something equivalent. Again in the formula given as in accordance with Stokes' law, the letter *g* was not acceleration but the force per unit mass in the centrifugal field. This was not the same numerically as acceleration, because steam was a resistant medium. In any case, the size of a drop determined whether Stokes', Newton's or a combination of both laws applied. Further, unless dryers of any type—augmentor, baffle or centrifugal—had a probably impossible 100 per cent. efficiency, some drops would always carryover at high steam output.

For centrifugal dryers, the available drainage head should include the kinetic head of whirling extracted water as well as the gravitational head, but mention of this kinetic head had been omitted in the remarks on page 65, whereas on page 63 there were the words, "the water is ejected from the cyclone into the water space by its own velocity head".

As regards space occupied, the cyclone dryers indicated in Fig. 14, along with the grids above them, took up a great deal of space. If as much space were allowed for dryers fitted above the water level, the pressure loss could be brought down to a very low figure, which would make the drainage head ample for dryers even of the non-centrifugal type.

The writer was responsible for the design of the dryer illustrated in Fig. 20. The space for its accommodation was much restricted due to the presence of a structural member. Thus, the body size with relation to pipe bore was a good deal less than normal. Even so, the dryer had a good efficiency. But one of usual proportions taken from stock, 3in. size, when tried with air (for convenience) at any speed from 30 to 250 f.s. and containing two to three pints per minute of fine water spray delivered from an oil burner, gave an extraction that was almost if not quite 100 per cent., because no drops could be detected in the air discharge.

Steam wetness values should always include a margin for errors of determination, because it was practically impossible to eliminate errors completely. The writer's experience of throttling calorimeters had been that dryness determined from them could not be relied on to closer than ± 0·2 per cent.

Mr. A. L. Mellor (Messrs. Yarrow & Co., Ltd.) wrote: In the table on page 62 the maximum wetness of steam from various types of boilers was given. It was stated that in the case of an Admiralty three-drum boiler and a La Mont boiler fitted in the S.G.B., the maximum wetness was nil. The writer suggested that this was an impossible attainment in these boilers. The most serious misstatement was the figure given for the Yarrow controlled superheat boiler for which the maximum wetness was stated to be 0·8 to 1 per cent. The figures which the Engineer-in-Chief's Department of the Admiralty had showed that before the Vortex dryer the dryness was 99·62 per cent. and after the dryer 99·9 per cent. This was at full output and with the water level slightly above the designed water level. It would be unfair to the type of dryer fitted to allow this misstatement to go uncorrected. The type of dryer fitted to the Yarrow controlled superheat boiler was shown in Fig. 20 of the paper. The writer did not know how the author arrived at the figure of 23·5 sq. ft. for the net water plane for this boiler, but the fact as stated above that the steam was 99·62 per cent. dry before the dryer supported the writer's contention that this estimate was very much on the low side.

The figures given above for the Yarrow controlled superheat boiler could be compared with those for the Foster Wheeler controlled superheat boiler, as they were taken under similar conditions.

It was submitted that the most satisfactory type of steam dryer was the one which caused the least interference with the accessibility in the drum, and in the design of Yarrow controlled superheat boiler, the time required to make all parts accessible for cleaning or inspection had been reduced to the minimum. This aspect was of great importance in boilers for the Mercantile Marine.

Mr. S. B. Jackson (Member) wrote: With *perfectly pure water* it could be shown by thermodynamics that if a drop were formed in the saturated vapour or projected into it, it would evaporate and flash into vapour with very great rapidity, and also that a drop of water could not exist in an environment of saturated vapour. When the drop and the vapour were at the same temperature the drop could only be formed if the vapour was supersaturated.

But, nevertheless, there were drops in the vapour in the steam space, and it was pertinent to search for the cause since theoretically no drops should occur.

If perfectly pure water was projected in the form of drops from the water surface, it would be vaporized in the superheater and no deposits either in the superheater or on the turbine blades could possibly occur, so carryover and priming did not matter. Where water of the highest purity was employed as boiler feed, incrustation would be eliminated and even the fall in superheat temperature due to carryover could be designed against in such circumstances. Carryover was always found when soluble salts were present with solid suspended matter. Maintaining the total dissolved solids below a certain concentration was only a palliative.

In his view, more adequate water-conditioning equipment was necessary, and it was in this direction that the most beneficial results would be obtained. All experience confirmed this. To state that "the effect of normal impurities in a boiler is very small and they cannot influence carryover to any great extent" was not borne out by the facts of land practice, where the boiler was stationary and the operating conditions much more favourable from carryover considerations than in marine practice.

Regarding Fig. 1, all curves for the various pressures showed that at zero velocity of rising steam the maximum height of projection of the drops was in the neighbourhood of 2in., although they had no projection velocity—and hence, force—to raise them. From the information given by the curves, zero drop height at zero projection velocity was only obtained in the vicinity of the critical pressure. All curves should have their point of origin as zero if the equation upon which they were based was valid. At pressures just above atmospheric the curve was nearly a straight line, and the drops would be projected about 4in. above the surface with zero projection velocity, and at 3·0ft. per sec. about 7in. The vertical portions of the curves needed some explanation as the conditions they purported to portray envisaged some very curious results, and he suggested that the figure did not agree with the actual facts.

The Author's Reply to the Discussion.

The author, in reply, agreed with Mr. Sampson that the table in the paper should be extended to include mercantile practice. This was now done and the table below represented current marine practice. So far as the limiting ratings were concerned, the first Admiralty design quoted could be taken as representing that limit without serious internal complications, but at higher pressures reduction in drum sizes to combat increasing thickness would almost certainly necessitate the acceptance of internal fittings. In this connection it might be of interest to record that during the war the additional total time allowed for removing and replacing internal fittings was 12 hours in Naval boilers.

Boiler		Babcock controlled superheat With cyclones		Two-drum boiler With baffles	Two-drum boiler With cyclones	Foster Wheeler two-drum
Load		Full power	60% overload	Full power	23% overload	Full power
Output...	lb./hr.	160,000	260,000	65,000	80,000	40,000
Wetness	—	—	0·25	>0·25	<0·1	nil
Drum pressure ...	p.s.i.	600	600	400	400	470
Drum diameter ...	ins.	50	50	42	42	42
Gross water plane *GP*...	ft.^{2}	32·7	32·7	20·8	20·4	35
Net water plane *NP* ...	ft.^{2}	—	—	—	—	—
Mean release rate on gross area	$\frac{\text{lb.}}{\text{hr.ft.}^2GP}$	4,900	7,950	3,120	3,920	1,140
Mean release rate on net area	$\frac{\text{lb.}}{\text{hr.ft.}^2NP}$	—	—	—	—	—
Volume of steam space	cu.ft.	53·4	53·4	34·1	20·1	48
Volume rating... ...	$\frac{\text{ft.}^3}{\text{hr.ft.}^3}$	2,180	3,530	2,120	4,400	792
Height of orifice above water level	ins.	24	24	23	15	21

The author could not agree with Admiral Dight that it was "natural" for there to be a fall in superheat. The natural law resulted in a rising characteristic for a convection superheater as shown in Fig. 32, and only the influence of priming caused the fall in superheat. In point of fact, modifying the augmentors in H.M.S. *Kelly* and Class resulted in an increase of 35-40° F. in steam temperature. This in turn represented an increase in endurance at full power of about 1·5 per cent.

The correction to the constant 12·35 supplied by Mr. Davis and Mr. Alexander was interesting, as it provided an explanation of the fact that the observed inception of carryover occurred at slightly higher ratings than those previously obtained by direct calculation.

The evidence quoted by Mr. Zoller on German experiences at high pressures could not be taken as indicative of the difficulty in obtaining dry steam, as the vast number of circulation failures tacitly accepted by the Germans would suggest that they did not appreciate the significance of the many problems in boiler design. Mr. Zoller had over-simplified the ease with which cyclones might be removed from the drum, as it would still be necessary to strip down the baffle system for an adequate inspection of the heating surface. He was correct in stating that caustic soda did not "crystallise" out after evaporation, but this did not in any way invalidate the argument regarding the objectionable nature of deposits.

The particulars of the boiler quoted by Mr. Hayden had been added to the table on the assumption that he meant *gross* release area and not net area as stated. The net area for such a design would be about one-third to a quarter of the area quoted, depending upon design details not stated.

So far as experience with Admiralty boilers was concerned, no differences in superheat due to spraying the feed through the steam space had been observed. In a boiler tested with drowned feed pipes, with pipes in the steam space and with feed pots, no differences were recorded.

Mr. Hayden's comments on the design of valve for the Tracy purifier were noted, but in the absence of concrete evidence substantiating the claims, the author doubted whether the weight and inertia of the valve could be overcome without decreasing the already small head for drainage.

The difficulties in using a throttling calorimeter quoted by Mr. Hayden were undoubtedly true, but a further complication was the uncertain loss due to the change in velocity head of the steam. With a changing wetness, the reconversion of water to steam was uncertain owing to the effects of supersaturation and thus further complicated the problem of *temperature* measurement.

The relative values of the gravimetric and calorimetric methods of determining wetness appeared to be difficult to elucidate. Admiralty experience was that the solids carried with the water were rather more concentrated when leaving the boiler than in the general boiler circuit; therefore, one would expect that the determination of wetness by a method based on the estimation of the actual solids would give a wetness higher than that obtained from the throttling calorimeter, but that was not the case. The gravimetric method always gave an answer below that of the throttling calorimeter, even when the basic zero error at low outputs was taken into account.

The author agreed with Mr. Plummer that the initial downward

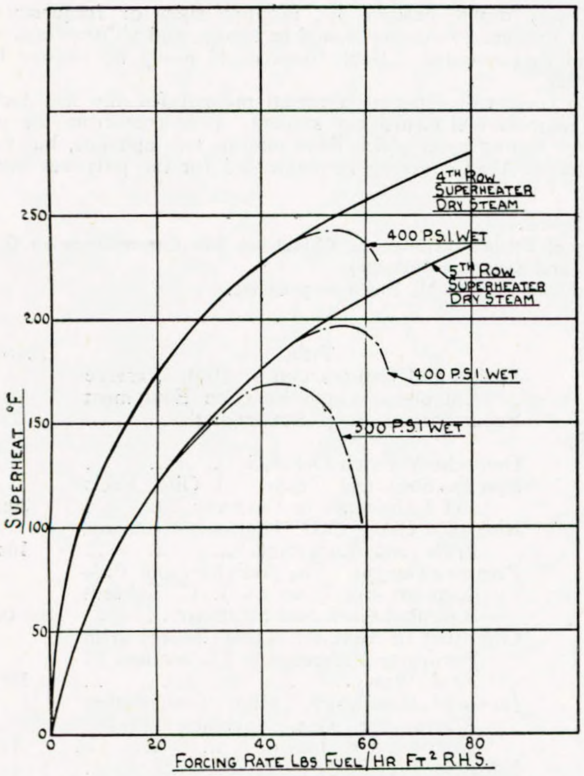

FIG. 32.—*Variation of superheat with boiler rating and position of superheater.*

velocity of the mixture in La Mont boilers would delay the inception of carryover due to projection of droplets. The steam must, however, be released from some surface and the mode of projection of the droplet by the bursting bubble would, therefore, still apply.

Mr. Plummer's suggestion of a double baffle arrangement to be applied to the three-drum boiler was interesting and worth development.

The author was interested in the satisfactory use of the dionic method reported by Mr. Richardson and Mr. Plummer. The Admiralty had attempted to carry out some trials with this method, without satisfactory results however, and the experiments had not been continued.

The point made by Mr. Richardson and others about the uniformity of take-off applied more particularly to land-type boilers, where heating was more uniformly spread over the length of the drum than was usual with the more highly-rated Naval boilers. It had been conclusively shown, as stated by Mr. Hayden, that for end-fired marine boilers there was an optimum position for the *whole* take-off, and any attempts at uniform take-off only resulted in greater wetness being experienced (except in the case of "cyclones").

The author agreed with Mr. Alexander and Mr. Davis that the precise laws governing carryover must be between the two extremes.

The water level, although not stated, was indirectly given in the table by the distance from the water level to the offtake. The reason for the difference in behaviour of various boilers was, of course, the difference in internal fittings. The boiler adversely affected by low water level (due to uncovering the perforated plates) was also adversely affected by a water level 8in. above normal water level, due to the close proximity of the offtake.

The augmentor was primarily a device for aiding circulation and its influence on wetness was incidental. The author saw no reason why a similar dryness figure should not be obtained without an augmentor and with no additional internal fittings. It was agreed that the drop size at the moment of projection was an unknown factor, but the fact remained that there was no determinable wetness on the trials reported and the author's statement had not been challenged by any of the witnesses of those trials who had contributed to the discussion.

Mr. Alexander was quite correct in saying that ebullition caused the wetness, and the author's view was that it was wrong, in principle, to permit ebullition to cause wetness and then endeavour to dry the steam. It might be noted in passing that dryers could in fact increase the wetness if the pressure drop across the dryer was greater than the head available for drainage, *v.i.*

It was now usually accepted that a well-designed throttling calorimeter was accurate to ±0·1 per cent.

In reply to Mr. Mellor, the figures for the Yarrow controlled-superheat boiler were taken from the second and subsequent series of trials. It was agreed that on the initial series of trials, figures of 0·4 per cent. before the dryer and 0·20 after the dryer were obtained, but subsequent trials gave such figures as:—

Output	Water level in glass (in.)	Before dryer	After dryer
3/5	7	0·4	0·6
3/5 (repeat) ...	7	0·4	0·4
4/5	7·5	0·8	1·0
5/5	4	0·6	0·8
6/5	4	0·6	1·0
4/5	7·25	1·0	1·0
5/5	4·25	1·0	1·0
6/5	4·25	1·6	1·0

These figures were considered by the author to be more in line with those expected from a boiler at these ratings and as no explanation of these differences had been found, even after examination of the drainage pump, they were chosen in preference to the earlier set.

The carryover of pure water into the superheater could be objectionable notwithstanding the argument adduced by Mr. Jackson. When the quantity of water carried into the superheater was sufficient, the mode of heat transfer inside the superheater tube changed with a consequent fall in the metal temperature. This metal would then be subject to temperature fluctuations depending upon the amount of carryover, and failure due to fatigue would be relatively rapid. It was agreed that a detailed interpretation of the curves shown in Fig. 1 left something to be desired, but as the main interest was centred in that part of the curve where the rate of change of vertical ordinate was rapid and as the numerical values were in any case of minor importance, it was not considered necessary to dwell in detail on the precise implications of these curves.

The author agreed with the various speakers who considered that internal fittings should be kept to the minimum essential to ensure dryness, but it must not be forgotten that increasing pressures and increased savings in weight and space would eventually necessitate the use of internal fittings designed to ensure dry steam entering the superheater.

◆

Mr. A. F. C. TIMPSON, M.B.E.

That the quality and virility of a technical institution are a direct reflection of the calibre and efforts of those members who serve as office bearers is self-evident. Therefore, it will not be surprising to those who are familiar with the reports of the Institute's work for many years past, that the records of the Institute contain some remarkable, perhaps unparalleled, examples of sustained and disinterested service by its office bearers.

Following the outstanding example of Mr. Alfred Robertson, C.C., who was the recipient of a presentation in 1944 on the completion of 25 years in the office of Honorary Treasurer, a second remarkable instance is that of Mr. A. F. C. Timpson, M.B.E., who has just completed 21 years continuous service on the Papers and Transactions Committee, for the major part of which period he has been Chairman of the Committee.

To mark this notable event Mr. Timpson was entertained as the guest of honour at a dinner, provided by the Members of his Committee, at the Dorchester Hotel, Park Lane, on Wednesday, 2nd April, 1947. Amongst the other guests of the Committee were Mr. Alfred Robertson, C.C., Mr. J. A. Rhynas, Mr. H. S. Humphreys and Mr. G. Lambert.

Mr. G. R. Hutchinson, as a Member of the Committee in its infancy, occupied the Chair and made the first of many happy speeches congratulating Mr. Timpson on his achievement. He was followed by Mr. A. C. Hardy, B.Sc., whose association with the work of the Committee also went back to its earliest days, and by Mr. Robertson, Mr. Humphreys and Mr. Rhynas.

Warm tributes to Mr. Timpson's ability and altruism, and to his high qualities as a chairman, were also paid by Mr. W. D. Heck, B.Sc., Mr. J. Calderwood, M.Sc., Mr. H. J. Wheadon and Mr. B. C. Curling (Secretary).

Mr. Timpson expressed himself as being overwhelmed by the flattering recognition which had been accorded to his efforts, but reflecting on the progress which had been made during the past 21 years he felt that the work of his colleagues and himself had had very satisfying results.

ADDITIONS TO THE LIBRARY.

presented by the Publishers.

Sailing and Motor Cruising on the South Coast.

By K. Adlard Coles. Charts and drawings by T. L. Stocken. Faber & Faber, Ltd. London, 1947. 144pp., profusely illus., 8s. 6d. net.

The numerous harbours and anchorages between Dover and Penzance are the main concern of this book. Written by a well-known yachtsman, it contains a host of sailing directions and tidal information that will be found extremely useful by anyone cruising on the South Coast in a small craft. Sailing directions that are produced under official auspices are intended for use on large vessels, and the suitability of a harbour is judged and graded according to its size and commercial facilities. Any approach to a lesser port is apt to be couched in tones of considerable gloom and despondency. At times, these become positively blood curdling and the amateur sailor is left with the impression that he should give such a place an offing of several miles.

It is a refreshing contrast to find that Mr. Adlard Coles writes in a vein of cheery optimism about the many delightful little havens along the South Coast. He does not even shrink from taking us into Mousehole or Mevagissey. Nor does he consider it a sign of lunacy to cherish an ambition to "make" Beer. After all, it does sound much better to be able to head a log sheet, or a letter, "IN Beer" and not the far less satisfactory "OFF Beer".

The author is apparently a geographical purist as he starts at Dover and not just round the corner at Ramsgate. From the yachtsman's viewpoint, Ramsgate is much the better port for a stay of more than a few hours. Dover is too large and the shops are too far away. In pre-Shinwell days there was also a risk of acquiring a coating of coal dust by anchoring too near the transporters.

On occasions, the author is perhaps a trifle too encouraging. About Beaulieu, he writes "The entrance is not difficult and is available to most vessels except at exceptionally low spring tides". This is quite true for anyone who knows the place and has not too large a craft. On the other hand, the bar only carries about ¾ fathom at L.W.O.S. and it is a little harrowing for a stranger to find that he has to head straight for the beach and then make a turn of over 90 degrees at the very last moment. A further difficulty which the author could not have foreseen is that the recent storms have carried away most of the seamarks and perches.

The book is profusely illustrated by plans, "chartlets" and photographs.

Electric Wiring Diagrams.

By G. E. Stubbs. E. & F. N. Spon, Ltd. London, 1946. 40pp., 75 figs., 3s. net.

This booklet of Wiring Diagrams, many of which are ingenious, whilst primarily intended for land-work will also be found to be of considerable assistance to those engaged in the arrangement of and upkeep of marine electrical installations.

Diagrams Nos. 1-35A are concerned with the control of lighting circuits, including multiple-point control and arrangement of dimming. Whilst the majority of these diagrams are applicable to land-work, a number will be useful for marine work.

Diagrams Nos. 36-45.—These diagrams deal with bell circuits and are more or less universal.

Diagrams Nos. 46-54.—The arrangement of these diagrams, which relate to rotary switches, are useful as a method of reversing motors and of obtaining varying degrees of heat for heating, cooking and similar circuits.

Diagrams Nos. 55-58 showing the arrangement of charging circuits, are clear and useful.

The remainder of the diagrams, whilst being interesting, do not at the present stage contain much of value to those engaged on marine installations

Electrical Testing for Practical Engineers.

(Second edition). By G. W. Stubbings, B.Sc., F.Inst.P., A.M.I.E.E. E. & F. N. Spon, Ltd. London, 1947. 266pp., 114 figs., 12s. 6d. net.

This work deals in a practical manner with electrical instruments and test gear and the general techniques required in the testing of various types of electrical equipment. There are a few faults in the diagrams; for instance transformer windings should be drawn the correct way round, positive and negative signs or frequency signs showing the type of current should be shown, and all drawings should conform to convention. Such items could easily be verified before re-printing.

The book will serve as a useful manual for the less technical works engineer and elementary student. It is free from the mathematics of testing upon which there may be two opinions, but for the more general user it can be recommended for the purposes intended.

Purchased.

Reports of British Intelligence Objectives Sub-Committees on German and Japanese Industry.

Published by H.M. Stationery Office.

No. of report	Title.	Price, net.
F.I.A.T.		
611	Design and Construction of High Pressure Compressors and Reaction Equipment	4s. 6d.
620	Supercharged Loop Scavenging	1s. 6d.
B.I.O.S.		
590	Deutsche Vacuum Oel A.G.	6d.
771	Specifications and Testing of Oils, Fuels and Lubricants in Germany	20s. 0d.
1008	Rhenania Ossag A.G. Hamburg-Germany. Fuels and Lubricants	16s. 0d.
1109	Pressure Gauges. The Activities and Products of the Firm of J. C. Eckardt A.G. Bad Cannstadt Stuttgart	1s. 0d.
1173	Corrosion of German Naval Boilers with Particular Reference to De-aeration of Feed Water	18s. 0d.
583	Japanese Metallurgy. High Temperature Alloys for Gas Turbines, Rocket Nozzles and Lines	1s, 6d.
613	Japanese Welding Standards	1s. 0d.
756	Characteristics of Japanese Naval Vessels. Portable Gasoline-driven Pump Unit	1s. 0d.

MEMBERSHIP ELECTIONS.

Date of Election, 5th May, 1947.

Members.

Kenneth William Cartwright.
Richard Gilbert Cook, Lt.-Com'r(E), R.N.(ret.).
William Stevenson Cuthbertson.
Alwyn James Edwards.
Charles Foster.
George Gibson.
George Hackston.
Christopher Mildmay Hall, Com'r(E), R.N.
Alan Huntingford.
Frank Albert Lamb.
Gilbert Ashton Plummer.
John Sloss.
Ronald Smith.
Arthur Stanley Thomas.
Sydney Walker.
George Lambert Whyte.
Daniel McNeil Wignall.
Ronald Edwin Wootten.

Associates.

Bernard Allen.
Patrick William Clarke.
Alexander Leslie Greig.
Arthur Harvey Hignett.
Humphrey Richard King.
James Stuart Mason.
Reginald William Parsons.
William Gresham Stevenson.

Students.

Ejaz Ahmad, B.Sc.
Peter Meyrick Threlfall, B.Sc.

Transfer from Associate to Member.

Henry Alcorn.
Thomas Douglas Joffre Hall.
Keki Rustomji Vesuna.
James Alexander Winton.

PERSONAL.

(When notifying changes of employment, members are requested to state whether they are agreeable to the information being published in this column.)

Alex. Cowley (Member) of Liverpool has now been assigned to the duties of production officer in the Directorate of Royal Engineers Equipment in the Ministry of Supply.

T. W. Longmuir (Member) has been appointed Head of the Mechanical Engineering Department of the L.C.C. School of Engineering and Navigation.

D. R. West (Associate) has been appointed as a maintenance engineer with Messrs. Frazer & Co. (Nelson) Ltd.