PRIMING IN BOILERS.

Engineering progress has of recent years made great strides, the advent of new and improved forms of boilers and prime movers having been accompanied by the almost universal introduction of superheated steam and the use of higher boiler pressures. There is, however, at least, one important exception to the general advance, and one which till recent years has attracted comparatively little attention: thus while much thought and skill has been devoted to the art of generating steam, the quality of the product has been almost completely ignored.

In 1893 Stromeyer, in his work on Marine Boilers, stated that information on the subject of priming was "almost non-existent," while at the present day it may be said that foaming and priming are the least understood of boiler phenomena, despite the comparative antiquity of the subject.

The passage of water in the steam from the boilers not only materially reduces the efficiency of the turbines but also results in increased loss from leakage and drainage, while, apart from the possibility of actual damage to the machinery as the result of priming, moisture particles may carry over scale-forming material into the highly heated superheater tubes with risk of shortening the life of these parts. Finally, the passage of water into the superheaters will reduce the temperature of the steam at exit, it being estimated that 1 per cent. of moisture reduces the superheat by some 14°F., corresponding to an addition of about 1 per cent. to the fuel expenditure.

There are thus very real reasons why the question of priming is becoming a matter of some importance, and it is of interest to review the present state of knowledge on this subject.

Engineers and scientists have expended much effort in the past in attempting to define "priming," and it is evident that considerable confusion of thought exists. The scanty literature on the subject indicates that authors employ the terms "foaming," "priming" and even "entrainment" interchangeably, making it difficult to understand what is meant unless the terms are clearly defined.

The term "priming" is customarily employed by engineers to describe the passage of water in the steam from a boiler or other generator, and the word will therefore be employed in the foregoing general sense in this article.

The phenomena, which are to be discussed herein under the general heading of "priming," appear, however, to be capable of classification into at least three fairly well defined groups, namely :—

(1) The formation of foam on the surface of the water. This foam may vary in thickness from a mere surface layer to a mass of bubbles completely filling the steam space.

(2) Rapid ebullition with the consequent passage of droplets of moisture into the steam pipe.

(3) A combination of both of the former phenomena, the boiling being so rapid that the whole mass of water is full of steam bubbles.

In view of this, it is here proposed to consider priming, or the passage of water in the steam, as being due to two effects which may be conveniently termed "foaming" and "entrainment" respectively, and of which the definitions follow, viz. :—

Foaming is the formation of a more or less permanent, continuous layer of bubbles covering the whole surface of the liquid, and is due at source to some particular property of the latter.

Entrainment on the other hand is a mechanical process, entailing the removal of drops of water by the velocity effect of the vapour with which they become intimately mixed.

Thus any liquid may suffer entrainment, while foaming is dependent upon the nature of the liquid, and, in considering cases of so called "priming," due regard must be paid to both effects.

Foaming.—The following general statement regarding the cause of foaming is due to Bancroft* and forms the best modern contribution to the subject :—

"To get a foam the only essential is that there shall be a distinct surface film, that is, that the concentration in the surface layer shall differ appreciably from that in the mass of the fluid. All true solutions will therefore foam if there is a marked change of surface tension with concentration . . . All colloidal solutions will foam if the colloid concentrates in the interface or is driven away therefrom. To get a fairly permanent foam the surface film must either be sufficiently viscous in itself or must be stabilised in some way, as by the introduction of a solid powder into the interface . . . Soap solutions foam when shaken and the foam is, or may be, quite stable owing to the viscosity of the soap film . . . Grease will help to stabilise a foam in some cases."

Experiments have been carried out (Ind. Eng. Chem. Vol. 16, pp. 1121–5) to apply this theory to the foaming of steam boilers, and it has been substantially confirmed thereby. It was found that most solutions of inorganic salts did not foam when boiled, but that the addition to such solutions of powdered insoluble material, even when comparatively coarse, caused foam by stabilisation of the surface film. On the other hand pure water does not foam, even with the addition of finely divided insoluble materials.

It was found that foaming does not occur in a clean boiler fed with softened water, even in the presence of a considerable concentration of soluble salts. A dirty boiler fed with the same water foamed freely on account of the disintegration of the scale.

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* "Applied Colloid Chemistry, General Theory."

Finally it was observed that foaming never occurred with saturated solutions of common salt (sodium chloride) or even with strong caustic solutions, *unless* solids or colloids were present in sufficient quantities to stabilise the film.

Naval boilers are generally operated with extremely weak solutions of lime, in which are suspended very finely divided oxides and scale of various forms, together possibly with particles of solid lime: the water may also be contaminated by salts in solution, derived from sea water, while oil or grease is likely to be present. The conditions in these boilers may therefore be favourable for the formation of foams, and there is sufficient evidence to lead to the conclusion that many cases of so-called priming can be traced at source to the practice of using unnecessarily large quantities of lime in the feed water.

The subject of foam formation is extremely complicated, involving laws regarding solutions and surface tension which are as yet but imperfectly understood, and it is not possible to state rules for the prevention of foam. Evidently, from what has been said, the removal of all insoluble material and the use of perfectly pure water should prevent the formation of foam, but this solution is impracticable in view of the necessity for preserving the water in an alkaline condition, the impossibility of completely preventing contamination of the feed by sea water and the inevitable presence of iron oxide in the feed.

In many cases, *e.g.*, in evaporators, the problem is not to prevent foam so much as to operate the apparatus with a liquid which is inherently of a foaming nature. Many evaporators in commercial work are required to work with liquids of far worse characteristics in this respect than is sea water; in such cases unskilled operation will result in the complete emptying of the evaporator in an extremely short space of time. A skilful operator adjusts his level to a height which permits of the foam being completely broken before it reaches the outlet, but if by too rapid boiling a coherent film of liquid rises too high the whole mass will boil over. Operation thus implies the control of two factors, level and rate of boiling—once the foam enters the steam pipe or vapour line there is little hope of stopping it unless a separator can be introduced, the proportions being so generous that the bubbles of foam can be broken.

The action of an efficient separator in breaking foam involves reduction in pressure sufficient to enable the vapour pressure within the bubbles to burst them; the pressure drop required is considerable however, in the order of 15 lbs. or more, and for obvious reasons cannot in general be provided for in steam pipe lines or in evaporators. If the foaming liquid can be driven against baffles with a sufficiently high velocity the foam may be broken, but the effect appears to be none too certain.

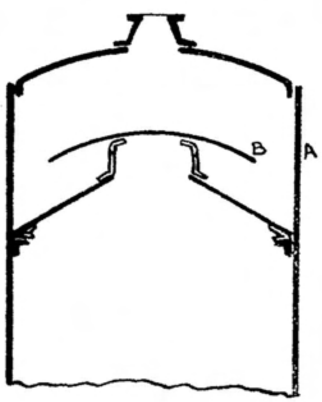
In certain industrial processes re-agents are added to the liquid to reduce the foam; thus in the sugar industry, where evaporation of a viscous liquid under high vacuum is carried out, it is the practice to provide so called " butter-cups " on the evaporators; oil or fat is drawn into the shell under vacuum, or forced in by a pump. The efficacy of this time honoured practice is undoubted but the mechanism whereby it achieves its purpose is obscure, although it has been suggested that in this particular case the oil throws out the solid particles in suspension at the surface of the liquid.

It appears that foaming is influenced by the degree of concentration of salts in solution in the feed, and also by the amount of the suspended solids and other offending matter present: thus an obvious remedy is to reduce the concentration by frequent blowing down, a practice which is not only wasteful, but also entirely impracticable in many cases.

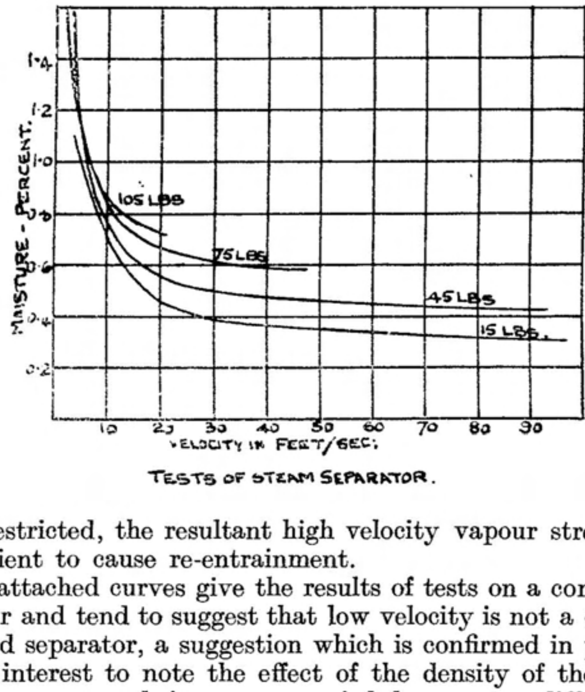
In locomotive practice, especially in U.S.A. and Canada, " anti-foam " compounds are regularly added to the boiler water, thus permitting operation to be continued with high densities without undue foaming. These compounds usually consist of emulsions of starch and castor oil, a mere trace of which, less than 0·001 per cent. by volume, causes instant disappearance of stabilised foams resulting from dissolved salts and suspended solids. There are a few other oils which appear to exercise a similar effect, but the inadmissability of any oil in a highly forced boiler forbids the use of such specifics for Naval purposes.

Entrainment.—The cause of this phenomenon is the lifting of drops of the liquid by the exit velocity of the vapour.

The effect differs essentially from that of foaming in that the suspended liquid may subsequently be removed from the vapour by mechanical means and it is upon this fact that most separators depend for their action; that is, they deal only with entrained water. If for instance the wet vapour is caused to flow rapidly around some suitably placed baffle the effect of centrifugal force will be to cause the particles of moisture to be separated toward the outer radius of the turn, where they may be collected by suitably placed baffles, or detached under the action by gravity.



In considering the design of separators the arrangements should be such as to prevent the separated moisture from dripping through a current of high velocity vapour, which will tend to pick them up again. Thus in some designs the vapour is projected against a baffle B, the principle being that once the drops come in contact with a wet surface they are not readily picked up again, while the combined effects of gravity and of their own momentum will prevent them from passing round the corner of the baffle, from the edge of which they are projected against the shell A. If, however, the space between A and B



TESTS OF STEAM SEPARATOR.

is too restricted, the resultant high velocity vapour stream will be sufficient to cause re-entrainment.

The attached curves give the results of tests on a commercial separator and tend to suggest that low velocity is not a criterion of a good separator, a suggestion which is confirmed in practice. It is of interest to note the effect of the density of the steam, a rise in pressure being accompanied by greater difficulty in effecting separation.

The internal steam pipe fitted in most boilers is designed to achieve its purpose by collecting the steam over a large area, and thereby reducing the velocity at all points over the surface of the steam drum.

Theory indicates that apart from the effect of velocity the amount of entrainment should increase (*a*) the less the difference between the densities of the fluid and the vapour; (*b*) the smaller the size of the drops; and (*c*) the greater the viscosity of the fluid. None of these is under control, neither can they be even estimated and thus the minimum distance between the surface of the fluid and the exit orifice is a matter of very considerable doubt, and but little experimental work appears to have been carried out on this question.

It may be observed that effects (*a*) and (*c*) are enhanced by operation at higher pressures, since both the density and viscosity of the steam are thereby increased. The size of the fluid particles is probably decreased by more rapid ebullition, providing thereby an explanation of the increased tendency to prime at high rates of forcing.

Entrainment will clearly be favoured by certain purely physical causes other than those mentioned, and among these the design and operation of the boiler are outstanding. The more complex the interior of the boiler, that is the greater the number of the internal fittings and of the generating tubes, the more likely is the surface of the liquid to be in a state of violent agitation, a condition which is also favoured by working at high rates of evaporation.

Violent ebullition may result from what is known as "bumping," that is, local superheating of the water, followed by a sudden evolution of steam. It is stated by some authorities to be comparatively common for the temperature of the water in a boiler to be two or three degrees Fahrenheit above that corresponding to the existing pressure: when such a state of affairs exists the sudden introduction of solid matter with the feed, the loosening of particles of scale, or a momentary reduction in pressure will result in a sudden collapse of the abnormal conditions accompanied by violent boiling.

No studies appear to have been made regarding the height to which drops of water are projected from the surface due to the bursting of bubbles, but it has been suggested that it may be possible to discover substances which, when added to the boiler water in the right proportion, would cause smooth boiling with little or no ejectment of liquid drops. The suggestion appears somewhat fantastic, and, unless experience with superheater tubes indicates the practical necessity for a great reduction in priming, little need exists for such investigations.

Little definite information is available regarding the minimum area of water surface for the liberation of steam and the least possible distance between water level and exit orifice if priming is to be avoided under given conditions. The result of this lack of knowledge is the existence of a number of theories which do not appear to have any substantial foundation in fact. Thus it is sometimes stated that a rise of 1 in. and 2 in. above the normal water level will result in priming, owing to the reduction in the liberating surface for the steam. A simple calculation will indicate that in a normal 50 in. steam drum the reduction in water line area under such conditions is about $\frac{1}{3}$ per cent., while in order to reduce this area by 50 per cent. it is necessary to raise the water level by some $21\frac{1}{2}$ inches. It may be noted in this connection that in Yarrow boilers the normal water level is below the horizontal diameter of the drum; a rise in level under these conditions is accompanied by an increase in water line area.

The extent of the so-called liberating surface is by no means certain, but it appears likely that this is little in excess of the area through the boiler tubes: the probability of this statement will be seen if steam is discharged from a tube into a beaker of water, when the bubbles of steam do not appear over the whole area of the water line but only over a limited area very little larger than that of the tube. The greatest tendency towards entrainment will probably exist therefore above the fire row tubes where the rate of ebullition is greatest, and protection may possibly be afforded by baffling the collecting orifices so that access to the steam pipe by spray from the centre part of the boiler is prevented.

Many devices have been invented with the object of preventing the passage of water from the boilers, but in nearly every case these are designed as entrainment traps only, and, as all have proved to be comparatively ineffective, it appears at least possible that in practice the factor of foaming is the more vital of the two effects.

Apparatus of this nature is, however, frequently effective in removing solid particles from the steam and thus serves a useful purpose in preventing serious deposits in the superheater tubes. The following analysis was taken from the sediment removed from a trial apparatus of this nature, the boiler having been fed with distilled water only and no "priming" having been experienced since the separator was installed.

Sample of Sediment.

Oil	2·84
Siliceous matter	3·71
Organic matter	10·06
Ferrous Oxide	7·21
Ferric Oxide	46·12
Zinc Oxide	5·73
Lime (CaO)	10·39
Magnesia (MgO)	7·38
Copper Oxide	0·15
Carbon Dioxide	5·74
Sulphuric Anhydride (SO_3)	1·01

Deposit had alkaline reaction.

The difficulties to be overcome in this respect as regards Naval requirements are not small, since it is essential that the weight of such fittings should be low, while their dimensions are argely determined by that of the manhole door; finally, the drop in pressure through these devices should not exceed 3 or 4 lbs./sq. in., which precludes the use of complicated baffling in a small space.

In certain existing service installations where severe priming was experienced it has been found of benefit to direct attention to the condition of the feed water; with really clean feed water and clean boilers the possibility of foaming is much reduced, and by attention to these points marked improvement can be obtained. In this connection it is pertinent to observe that the use of large quantities of lime to maintain alkalinity should not be necessary. One quarter to one half pound of lime added to each boiler (in the form of lime water) on each occasion of boiler cleaning, assuming that the boilers are then filled with freshly distilled water, has been found amply sufficient in many cases; it is suggested that if the need is found for greater quantities than this the cause of the acidity should be traced and remedied.