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THE DEGASIFICATION OF BOILER FEEDWATER

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The paper deals with the fundamental laws governing the operation of a method of degasifying water fed to boilers and economizers by heating the water to a temperature of some 25 deg. fahr. above the temperature at which it is to be deaerated and then suddenly introducing this water into a chamber in which a vacuum is maintained by a condenser and an air exhauster in series. The successful operation of the process depends upon (a) the inevitable reduction of solubility of dissolved gases in the water with increase of temperature (b) the explosive boiling caused by the rapid injection of heated water into a zone of lower boiling temperature and (c) a method of control and agitation of the water subsequent to the explosive boiling in a reduced air tension. The paper discusses the problem of eliminating air from feed-water in different types of heaters.

DEAERATION of the water fed to boilers and economizers for the prevention of corrosion is now a commercial realization. Engineering experience has also established empirically the degrees of degasification required, and indicated broadly the field in which it will be useful. One method among several which have met with success has been discussed from these relationships by the author in two previous papers,¹ and he proposes here to deal with the fundamental laws governing the operation of this method, and to indicate the extent of their application to conventional types of feedwater-heating equipment.

2 The method of degasifying water referred to above consists in first heating it to a temperature some 25 deg. fahr. above the temperature at which it is to be deaerated, this latter tempera-

¹ Trans. Am. Soc. M. E., vol. 42, p. 267; and MECHANICAL ENGINEERING, vol. 43, no. 5, p. 319.

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ture being selected by reason of operating conditions. The heated water is then suddenly introduced into a chamber in which a vacuum is maintained by a condenser and an air exhauster in series. The vacuum is so correlated with the heater temperature that the water entering the deaëerator chamber is superheated roughly 25 deg. above the temperature of the vacuum. This superheat energy produces a partial flashing into steam, and a pulverization of the liquid as it is suddenly injected. The steam, from the instantaneous boiling, enters the condenser, which is cooled by the supply water on its way to the heater. The heat liberated is recovered by the condenser and recirculated back to the heater. The non-condensable gases originally dissolved are removed from the end of the zone of condensation in the condenser by the air exhauster.

3 The process is significant in that it involves no heat losses. A small quantity of heat, amounting roughly to 25 B.t.u. per lb. of water handled, is continuously recirculated between deaëerator and heater, and any degradation of form which it suffers is not significant in heating processes. There are, however, energy charges in removing the water from the region of vacuum and in exhausting the non-condensable gases from the condenser.

4 The successful operation of this process depends upon three factors: (a) The inevitable reduction of solubility of dissolved gases in water with increase of temperature. This advantage is common to all forms of water-heating apparatus; (b) the explosive boiling caused by the rapid injection of heated water into a zone of lower boiling temperature. While only a very small amount of heat energy is involved, the rate of energy liberation is quite rapid, producing a boiling action, which is independent of diffusion currents within the liquid and results in a very effective disruption of the liquid; (c) a method of control and agitation of the water subsequent to the explosive boiling in a region of reduced air tension. This reduction of air tension is secured partly by the reduction of total pressure incident to the vacuum, and partly by the control of the boiling process to furnish a partial vapor component of total pressure to reduce the partial air tension, the sum of the two being equal to the pressure in the region of vacuum. Factors (b) and (c) in their application are unique with this apparatus, but the control of air tension is significant in any process of aëration or deaëration. This factor of air tension is the criterion by which to judge the performance of other types of

feedwater-heating apparatus from the standpoint of the removal of dissolved gases.

5 The solution of gases from the atmosphere, eliminating carbon dioxide which goes into chemical combination, follows Henry's law. The principal gases in air — oxygen, which produces corrosion, and nitrogen, which furnishes the bulk of the volume — have different solubility constants, and it is expedient, therefore, to consider the application of Henry's law to the individual constituents. Henry's law is formulated by Nernst¹ thus: "Gases dissolve in any selected solvent in the direct ratio of their pressures." When applied to a gaseous mixture this law may be made

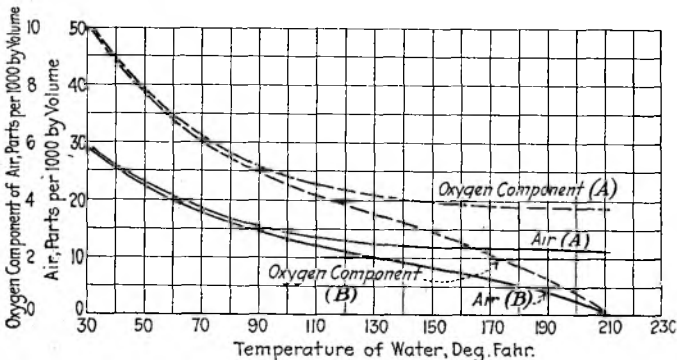


FIG. 1 SOLUBILITY CURVES FOR AIR IN WATER

[(A) Total pressure of air = 29.92 in. Hg.; (B) Partial pressure of air + pressure of water vapor = 29.92 in. Hg.]

more specific by saying that the solubility of any constituent is equal to a proportionality factor, which is different for each permanent gas and itself a function of the temperature multiplied by the partial pressure of the constituent. At any constant temperature the solubility of any constituent for purposes of engineering calculation varies directly as the partial pressure.

6 The solubility curves for air in water presented in Fig. 1 have been recomputed from the solubility data of Winkler. Two sets of curves are given, for both the oxygen component of air and for air, one set having been computed for a total pressure of air equal to 29.92 in. of mercury, and the other so that the sum of the partial pressure of the air and the pressure of the water vapor corresponding to the temperature will be 29.92 in. of mercury.

¹ W. Nernst, Theoretical Chemistry.

Obviously, in the first case the total pressure is indeterminate without calculation, and in the second case the same is true of the partial air pressure. However, the two groups of curves are useful, for between their intercepted ordinates lie the solubility values of air in water for any open feedwater heater operating on raw water and under atmospheric pressure.

7 It is characteristic of an open-type feedwater heater that it operates under atmospheric pressure irrespective of the temperature to which it heats, and that the supplies of water and steam are not interrelated. As a result the control of partial air pressure in the heater depends primarily on the control of venting

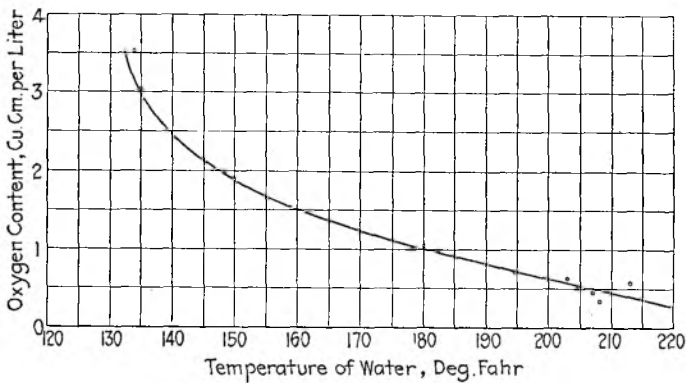


FIG. 2 DISSOLVED OXYGEN IN WATER IN OPEN-TYPE FEEDWATER HEATER IN REPRESENTATIVE CENTRAL STATIONS
(Heaters fed with condensate from condensers.)

if the heater is operated at a temperature close to the atmospheric boiling point. Invariably, there is a high air tension and a very considerable saturation if the heater is operated appreciably below the boiling point. Fig. 2 gives the result obtained from various types of such heaters fed with condensate from surface condensers. The data plotted were collected in a general survey of representative central stations scattered over an area east of the Mississippi River and are indicative of the average performance.

8 One point on this curve, however, is taken from a thoroughfare heater operating at 208 deg. fahr. This heater was installed in a blast-furnace boiler plant, and the entire exhaust of the blowing engine was discharged through the heater. This corresponded to a more extravagant venting than is permissible in standard

practice, but it indicates decisively the results a heater may give under proper reduction in partial air tension. All of the other heaters operate with the minimum amounts of venting consistent with temperature desired and in accordance with usual central-station practice.

9 The results to be expected from any standard heater operating with raw-water feed are illustrated in Fig. 3. One point is significant in this curve — that for an Elliott 1000-hp. open heater — and, in general, is applicable to all types of open heaters. There

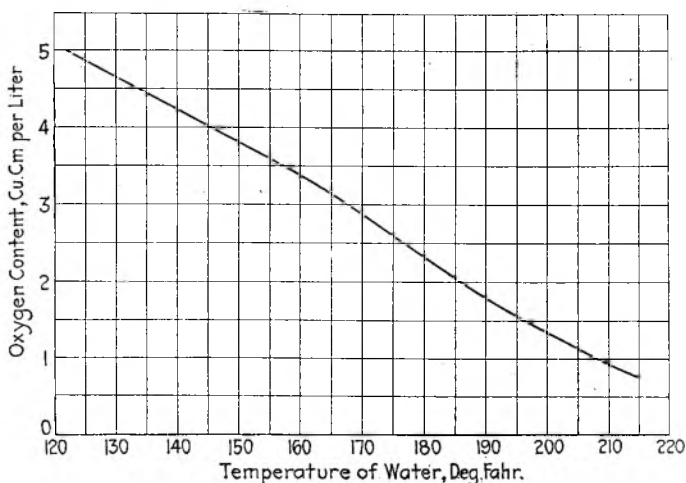


FIG. 3 DISSOLVED OXYGEN IN WATER IN STANDARD HEATERS OPERATING WITH RAW-WATER FEED

(Water saturated at 70 deg. Fahr.)

is a viscosity-surface tension relationship in water which prevents the liberation of air bubbles at temperatures below 160 deg. Fahr. As a result, unless considerable precaution is taken, the air-removal results for heaters operating below this temperature are very erratic and sometimes represent no separation at all. As temperatures rise above 160 deg. the solubility values more closely approach the theoretical, but in any event the equilibrium of solubility between gases and water is obtained very slowly, and accordingly, heater results even within this range are sometimes disconcerting. It is possible, however, to calculate, as in Fig. 4, the minimum solubility to be expected from an open heater. This calculation is primarily a proposition in air tension. It is very difficult, if not

impossible, however, to get a heater which will equal this performance on saturated supply water, and the curve, therefore, is only of suggestive significance.

10 The reason for the high values shown in the heater-performance curves is explainable from the curve of Fig. 5, which is plotted for vent mixtures from open feedwater heaters. It is an axiom in condensation work that the most efficient place for the removal of non-condensable gases is at the end of the zone of con-

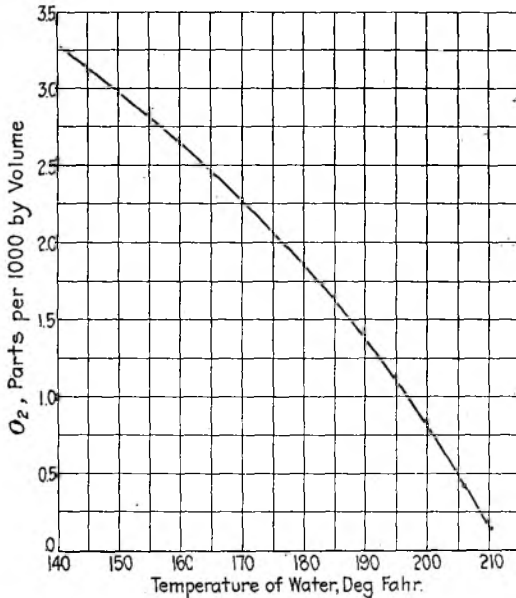


FIG. 4 MINIMUM OXYGEN SATURATION TO BE EXPECTED WITH AN ATMOSPHERIC OPEN HEATER

densation. Unfortunately, there is no correlated control of steam and water in an open heater, and as a result no definite zone of condensation exists; it is therefore necessary to consider air removal on a pure vapor-mixture basis. As a result, in order to adequately remove a pound of air, it is necessary to remove a very significant amount of steam, even though the actual quantity of air involved is small. This curve rises so rapidly at 210 deg. as to make adequate venting almost prohibitive from a heat standpoint. It is primarily for this reason that open heaters do not adequately solve the deaeration problem.

11 A series of curves analogous to Fig. 5 but for a condenser

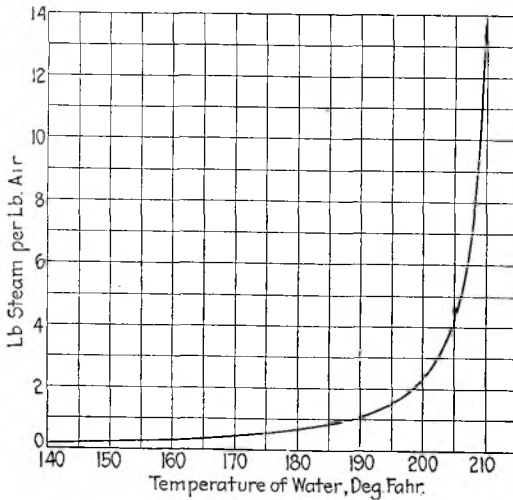


FIG. 5 AIR-STEAM RATIOS IN VENTING ATMOSPHERIC OPEN HEATERS

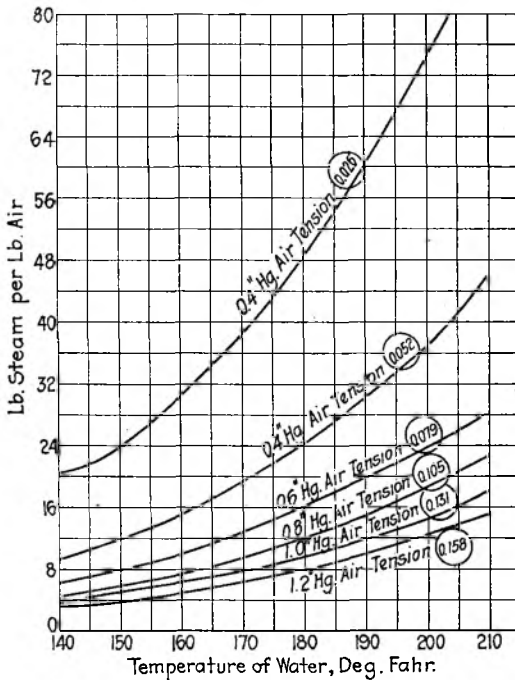


FIG. 6 AIR-STEAM RATIOS IN REMOVING AIR FROM JET-CONDENSER HEATERS

(Figures in circles are mean solubility values in cubic centimeters per liter.)

heater of the jet type, are shown in Fig. 6. Since these heaters operate under vacuum and with different degrees of air exhaustion, the curves are plotted for different air tensions in the condenser body. The condition of control of steam and water exists under the same unfavorable circumstances as in the atmospheric heater, and air-removal conditions are extremely severe. Therefore, the three upper curves, for 0.2, 0.4 and 0.6 in. of mercury air tension, are of comparatively little significance, and the expense of pumping out the air mixtures has practically relegated the zone of operation to air tensions within the zone of the three lower curves, for 0.8, 1.0 and 1.2 in. of mercury air tension.

12 In the open feedwater heater, venting is secured at the expense of steam only. In the jet-condenser heater, operating at vacuum, the vapor mixture must be mechanically exhausted. From a steam-ejector standpoint it requires practically as much energy to evacuate a pound of steam as it does a pound of air. Jet-condenser heaters have uniformly been more efficient aëratōrs than deaëratōrs, although their other merits are making their use extremely popular. In one installation, which perhaps may be said to represent the best from the standpoint of deaëration, the solubility of the water leaving the condenser is practically regulated by the condensate coming over from the main turbine condenser. In this case the jet condenser removes no air, but fortunately does not allow any to be added. It is also true that equilibrium between air and the solution of air in water is so slowly attained that spraying methods are uniformly unsuccessful in producing complete deaëration. There is, therefore, little probability that the jet-condenser heater, even with extravagant air-removal capacity, will offer a successful solution. It has, however, under the best conditions of heating, marked one step in advance, in that it has been found capable of preventing pollution of the water handled.

13 The use of surface-condensing apparatus has two inherent disadvantages. While the condensate or water which is to be heated does not come in contact with air, the use of such apparatus for exhaust steam from small turbines under modern boiler conditions is limited by the conductivity of superheated steam. The exhaust from small auxiliaries is so high in superheat under high boiler pressure and high boiler superheat that it is almost impossible to secure a workable conductivity without desuperheating. Where desuperheaters are employed or steam is extracted

from an intermediate stage of the main unit within the saturated zone, the problem is complicated by the aëration of the condensate in the heater.

14 Fig. 7 indicates the analogous condition of control of air tension in the deaëration process previously described. The scale of ordinates for these curves is inches of mercury air tension, and the scale of abscissas the B.t.u. drop in the instantaneous boiling. The various curves range between the maximum and minimum

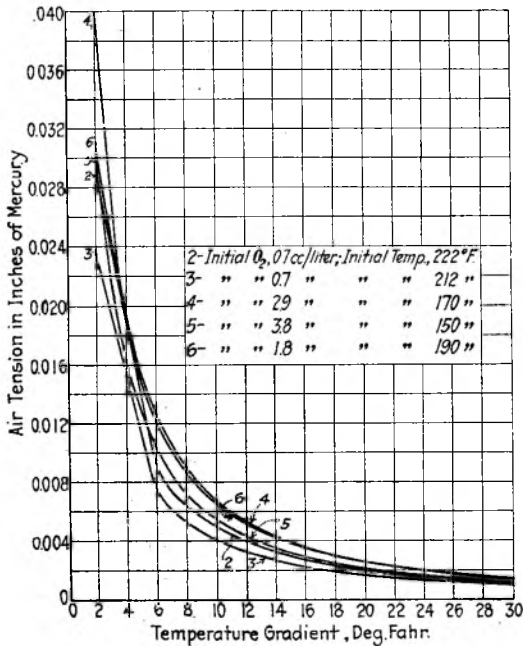


FIG. 7 CHARACTERISTIC CURVES OF DEAÉRATOR DESCRIBED IN TEXT

operating temperatures employed in the process and for initial air contents which ordinarily accompany these temperatures in feed-water heaters of the open type. Obviously, the closed type merely retains the air content of the water entering it. It is a fortuitous circumstance that the natural coördination between normal air contents in heating apparatus and vacuum are such that these curves even for widely different conditions are approximately parallel and lie within the same zone. The minimum air tensions in the operating range amounting to less than 0.002 in. of mercury, indicate very forcibly the reason for the effective results which are

secured by this process. However, the results which are theoretically obtainable are decidedly lower than the results actually obtained. The water is handled in the region of vacuum by agitating pans, which as a general premise are very much more effective than any type of spray nozzle. These curves are not in any sense an exposition of the completed operation of the deaeration process under consideration, but they do explain very satisfactorily and very accurately the underlying principles upon which successful operation is based, and indicate in radically new ways the relation of these principles to other features of power-plant apparatus.

15 Some mention was made in an earlier paragraph of the fact that a gradient of 25 deg. was employed between the heater and the deaerator. For all conditions of pressure the characteristic curves become practically parallel to the axis of abscissas in the neighborhood of 25 deg. There is no appreciable gain from increasing this value and it is economically wrong to extend the range of temperature gradient unless it be for some purpose of regulation as a part of a complete power plant. It is true, however, that the process does not operate efficiently at heater temperatures below 160 deg. fahr., and in case it is desired to go to operating temperatures on the deaerator as low as 130 deg. fahr., the temperature range must be extended beyond 25 deg., regardless of economic proportioning.