the amount dissolved in the condensate may therefore approach, or even exceed for short periods, the amount entrained by the steam.

CAUSES AND PREVENTION OF SCALES AND SLUDGES

Scales may be formed on surfaces of equipment in contact with water, and sludges in the body of the water, by the separation from the water of dissolved or suspended solids. According to the nature of a particular piece of equipment and the method of its operation, such separation may be promoted by one or more than one, of several factors:

a. The concentration of solids may be increased by the evaporation of water.

b. The dissolved solids may be rendered less soluble in the water by changes in temperature.

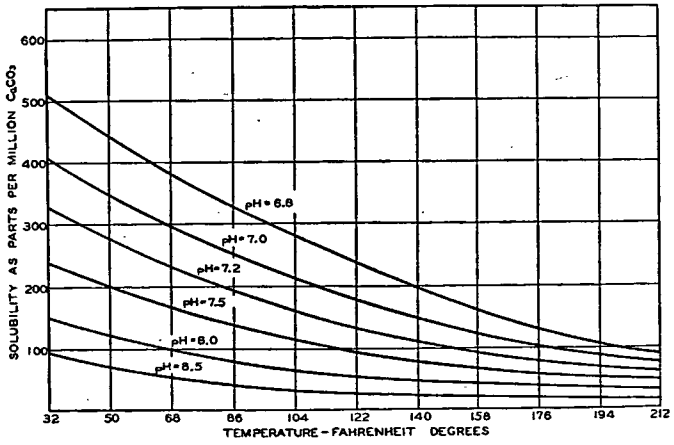

FIG. 2. SOLUBILITY OF CALCIUM CARBONATE IN DISTILLED WATER CONTAINING CARBON DIOXIDE

(pH Values at Approximately 73 F)

Fig. 2 Adapted from (1) *Ind. & Eng. Chem.*, 20 (1928) 1197—by Baylis. (2) J.A.C.S. 50 (1929) 2086—Frear & Johnson.

c. Conditions may favor the decomposition of unstable compounds with the formation of less soluble compounds.

Figs. 2 and 3 show that the solubilities of both calcium carbonate and calcium sulphate decrease with the rising temperature within a moderate range of temperatures. Surfaces transferring heat into water, such as condensers and coolers, are more susceptible to scale and sludge formation than are the cold parts of the same system using the same water.

The most common of the unstable soluble salts are the bicarbonates of calcium, magnesium, and occasionally iron. Under conditions favoring the removal of carbon dioxide, as when the water is strongly aerated or when it is boiled, the bicarbonates are readily converted to the relatively insoluble carbonates. The type of scale most usually encountered is

calcium carbonate (often called alkalinity) from the decomposition of calcium bicarbonate according to the following chemical reaction:

$$Ca(HCO_3)_2 + \text{heat} \rightarrow CaCO_3 + CO_2 + H_2O$$

Calcium Bicarbonate + heat → Calcium Carbonate + Carbon Dioxide + water

Conversely, carbonates are readily converted to the more soluble bicarbonate by the addition of carbon dioxide or other acidic materials. This explains the increase in the apparent solubility of calcium carbonate at decreasing *pH* values (increasing concentration of hydrogen ion) shown in Fig. 2, the carbonate really going into solution largely as bicarbonate.

In special cases, primarily with well waters possessing a high natural

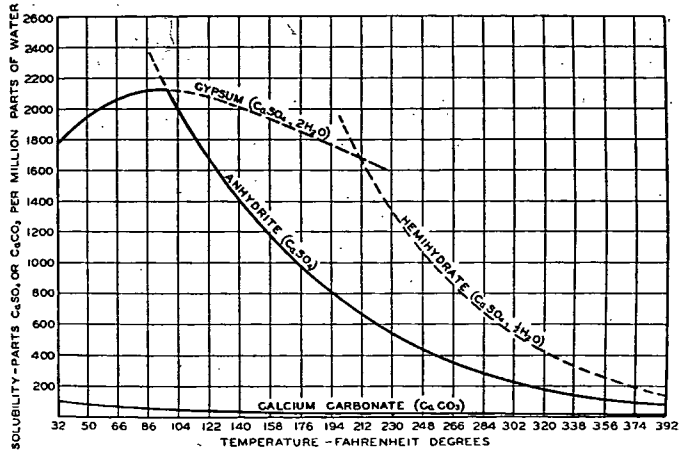

FIG. 3. SOLUBILITY OF CALCIUM SULFATE AND OF CALCIUM CARBONATE FOR COMPARISON

($CaCO_3$ in Equilibrium with Normal CO_2 Content of the Atmosphere)

Fig. 3 Adapted from Bull. No. 15, *Univ. of Mich.* Formation and Properties of Boiler Scales by P. E. Partridge.

iron content, deposition of iron oxide from the decomposition of ferrous bicarbonate takes place according to the following reaction:

$$4\,Fe(HCO_3)_2 + O_2 \rightarrow 2\,Fe_2O_3 + 8\,CO_2 + 4\,H_2O$$

Ferrous Bicarbonate + Oxygen → Iron Oxide + Carbon Dioxide + water

Low water velocity in heat transfer equipment often causes sludges to settle out in the tubes. This has the same effect on heat transfer as scale formation. When this occurs, increasing the water velocity often cures the condition.

It is sometimes desired to evaluate the tendency in a particular water toward the separation of calcium carbonate, which may be desirable as a means of establishing a corrosion-resistant film on metal surfaces, or in other circumstances may be undesirable because of the impedance of the calcium carbonate film to heat transfer. This tendency is indicated