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Loss in Pipeline Carrying Capacity Due to Carrasian and Tulerclulation

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URBANA

1960

 14
(27456—12-60)

Printed by authority of the State of Illinois

Loss in Pipeline Carrying Capacity Due to Corrosion and Tuberculation

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A paper presented on May 17, 1960, at the Annual Conference, Bal Harbour, Fla., by Thurston E. Larson, Head, Chemistry Sec., State Water Survey Div., Urbana, Ill. The study was supported in part by Research Grant 4007 from the National Institutes of Health, USPHS.

AN analysis of factors that result in a loss in pipeline carrying capacity must take into account: (1) the nature of the problem; (2) the fact that there is no cure-all or magic formula to remedy the problem, because the qualities of waters, like distribution systems, and even portions of systems, differ; (3) that corrective measures will increase the cost and effort of operations; (4.) that conditions of use affect the corrosive and inhibitive properties of water—that is, a water may have both corrosive and inhibitive properties at the same time, but its behavior will depend on how it is used; and (5) that considerable research is needed on the mechanics and chemistry of corrosion, as well as on associated tuberculation and its prevention.

For purposes of review, it should be pointed out that the carrying capacity of any pipeline or transmission line may be reduced in several ways, aside from blockage by silt and debris or from structural failure. Soft slime deposits may cling to pipe walls and develop wavy or ridged roughness. Such roughness often results in a much greater loss of capacity than is apparent from the thickness of the deposits. The deposits may consist of:

1. Bacterial growths, with or without iron and manganese

2. Soft deposits of aluminum hydroxide, resulting from improper filtration or from after-precipitation when coagulation is not effective

3. Soft deposits of magnesium hydroxide, resulting from ineffective coagulation or improper filtration.

Scale deposition may consist largely of excessive calcium carbonate or magnesium hydroxide at heating temperatures, of iron oxide as a loose or uniform deposition of corrosion product, or the deposits may come from natural iron in the water. With waters containing dissolved oxygen, tuberculation in the form of nodules or spicules may occur at intermittent locations on the pipe wall. Because tar-coated pipe is used extensively, it seems to be subject to difficulty more frequently than other materials; but with unstable waters, nodules and corrosion or dissolution can also develop on materials that are not ferrous. These latter types of resistance to flow of water and the effect of low velocities in dead-end areas merit discussion. It also seems pertinent to note that measures for the prevention of tuberculation involve measures for the prevention of corrosion.

Although these measures may prevent the occurrence of red water, tuberculation may still occur if the problem is not adequately dealt with.

Corrosion Inhibitors

Studies with aerated waters, made by the Chemistry Section of the State Water Survey Division at Urbana, Ill., have shown, without doubt, that each of three factors serves to inhibit corrosion rates.¹ These are calcium, alkalinity, and pH, usually in increasing concentrations. When their proportions are such that a condition of sufficient supersaturation exists with respect to calcium carbonate solubility, the tendency toward corrosion and tuberculation can be made essentially nonexistent. Tuberculation results when corrosion is almost, but not completely, prevented by this treatment. Further, when this proportion is such that the pH of saturation is low—that is, with more calcium and higher alkalinity—the saturation index necessary for protection approaches zero. But as the calcium and alkalinity concentrations decrease, it becomes increasingly difficult to overcome the tendency toward corrosion and tuberculation. Where such treatment is not applied to very soft waters, tuberculation results because of partial protection by the reaction of oxygen with the corrosion products.

Studies²⁻⁴ have also shown that alkalinity (greater than 100 ppm), in the *absence* of, or with very low concentrations of, calcium, serves as a weak inhibitor of corrosion, in contrast to the effect of chloride and sulfate ions. Inhibition is least strong at approximately pH 8.0-8.5, because, as indicated by Stumm,⁵ the buffer capacity of the carbonate-bicarbonate equi-

librium is decreased at the phenolphthalein endpoint by a factor of 10, relative to the buffer capacity at pH 7.0 and at approximately pH 9.5. With strongly buffered waters, as influenced by the alkalinity concentration and by pH, the ability of corrosion products—that is, OH⁻ at the cathode and H⁺ at the anode—to self-accelerate corrosion is less than with weakly buffered waters.

Calcium Carbonate Stability

It has also been demonstrated that the velocity of water flow influences the effectiveness of calcium carbonate stabilization and determines whether a stabilized water can cause tuberculation or a relatively protective action. These laboratory studies have been concerned with flat specimens of bare cast iron, exposed at room temperature to constant water velocities of 0.1-2.0 fps. The results, therefore, are indicative of, but only indirectly associated with, experience in the field. At each existing distribution system, however, the established principles concerning stability must be considered in relation to the prevailing environmental conditions.

It is time that the demonstrated principles of calcium carbonate stability and velocity be given a more complete evaluation, not only in relation to tuberculation and corrosion as they exist but also to corrective measures and to new installations or changes in water sources and quality. The principle of calcium carbonate stability is the one most widely applied and found to be most widely effective in treatment for the protection of distribution systems, although there are many notable exceptions to this principle.

Saturation Index

The equation for the saturation index was explained by Langelier⁶:

$$I = \text{pH} - \text{pH}_s = \text{pH} - K + \log \text{Ca} + \log \text{Alk}$$

in which I is the saturation index; pH , the actual pH ; and pH_s , the pH at saturation. K is $\log \frac{K_2}{K_1}$ (K_1 and K_2 are

thermodynamic constants, corrected for ionic strength and temperature).

The equation may also be expressed

$$\text{antilog } I = \frac{(\text{Ca})(\text{Alk})}{K'(\text{H}^+)} = \frac{\text{H}_2\text{CO}_3^*}{\text{H}^+}$$

in which K' is the antilog of K . These relationships exist:

$$\text{If: } I = 0; \quad \text{antilog } I = 1.0$$

$$I = +0.4; \quad \text{antilog } I = 2.5$$

$$I = +1.0; \quad \text{antilog } I = 10.0.$$

Another way of using this index is to relate the actual pH to the imaginary calcium and alkalinity concentrations that would exist if the actual concentrations were decreased by equal amounts until equilibrium existed with the actual pH . Then:

$$\begin{aligned} I &= \text{pH} - \text{pH}_s \\ &= K - \log \text{Ca}_i - \log \text{Alk}_i - K + \log \text{Ca} + \log \text{Alk} \end{aligned}$$

or

$$\text{antilog } I = \frac{\text{H}_2\text{CO}_3^*}{\text{H}^+} = \frac{K'(\text{Ca}_i)(\text{Alk}_i)}{K'(\text{Ca})(\text{Alk})}$$

If x is the excess of calcium and alkalinity, then:

$$\frac{\text{H}_2\text{CO}_3^*}{\text{H}^+} = \frac{(\text{Ca})(\text{Alk})}{(\text{Ca} - x)(\text{Alk} - x)}$$

and x , the **initial** excess, can be calculated. This method of calculation indicates a temporary excess but not the ultimate or equilibrium excess, which is always smaller.

Ryznar⁷ emphasized the importance of the concentrations of calcium and alkalinity to scale-forming properties:

Ryznar index

$$= 2\text{pH}_s - \text{pH}$$

$$= 2K + 2(\log \text{Ca}) + 2(\log \text{Alk}) - \text{pH}$$

or

$$\frac{\text{H}^+}{(\text{H}_2\text{CO}_3^*)^2} = \frac{(\text{Ca})^2(\text{Alk})^2}{(K')^2\text{H}^+}$$

Ryznar stated that the scale-forming tendency increased as the ratio of $\frac{\text{H}^+}{(\text{H}_2\text{CO}_3^*)^2}$ decreased from 10^6 (Ryznar index less than 6).

McCauley⁸ recently proposed a driving force index (DFI):

$$\text{DFI} = \frac{(\text{Ca}^{++})(\text{CO}_3^{--})}{K_s \times 10^{10}}$$

with which he precalculates the carbonate ion concentration from the alkalinity, pH and K_2' .

All of these approaches recognize a weakness in the saturation index as a direct criterion of the magnitude of excess calcium carbonate. Incidentally, Langelier never intended it to be such a criterion, other than as a relative indicator that was subject to interpretation. Langelier emphasized that the index "is an indication of directional tendency and of driving force, but it is in no way a measure of capacity."⁶

Caldwell and Lawrence⁹ established curves from which the equilibrium excess calcium carbonate could be determined for water at temperatures of 25°C and 100°C . These curves are not entirely adequate for waters at lower temperatures, but they are helpful because interpretations for other temperatures can be derived.

The relative excesses of calcium carbonate at 25°C (77°F) are shown in

Fig. 1. This is perhaps the best numerical indicator of the available calcium carbonate that may be expected from supersaturated water and is similar to the momentary index reported by Dye.¹⁰ The reaction rates, however, are still dependent on: (1) tem-

perature, (2) the influence of OH^- and H^+ developed at cathodic and anodic areas of the corroding surface, and (3) the buffering effect of greater concentrations of both calcium and alkalinity in the water. This buffering effect might be considered as the ability to maintain a potential or latent

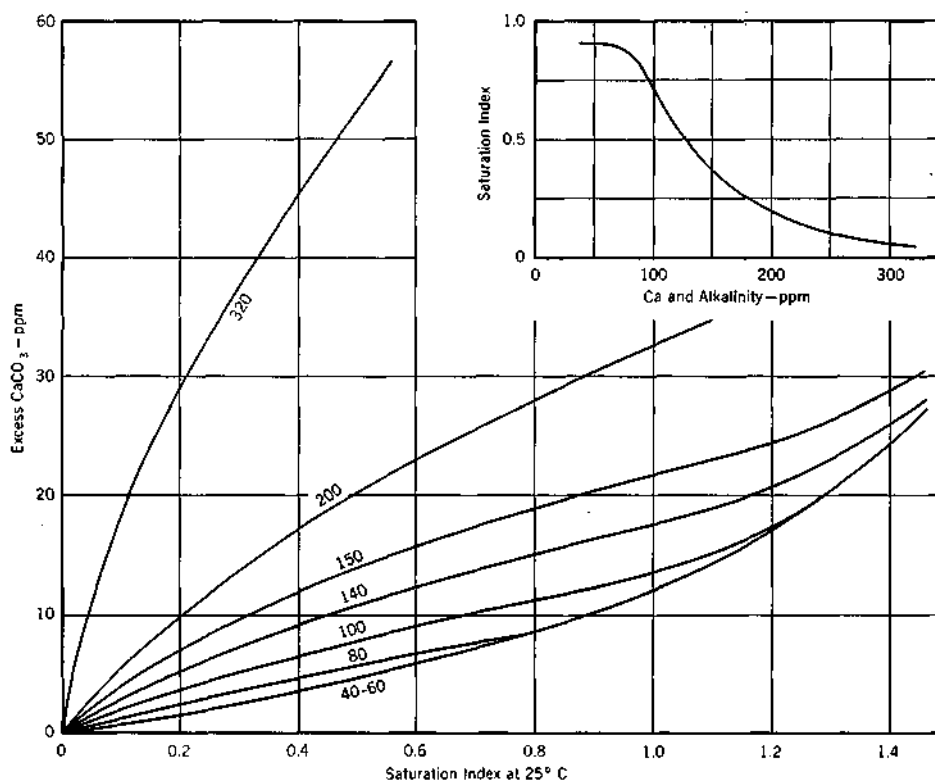


Fig. 1. Excess Calcium Carbonate From Supersaturated Water

The values on the curves represent equal calcium and alkalinity (as CaCO_3) concentrations in parts per million. The inset shows the curve for 10 ppm excess calcium carbonate.

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Velocity of Flow

Inevitably the distribution rate of protective components going to metal surfaces must be considered. Because metals react with water, the composition of the water—that is, H^+ and OH^- produced by corrosion reaction and side reactions—at the metal surface is

not the same as in the body of the water. The consistent failure to recognize this fact is perhaps the greatest source of misinterpretation of field experience. In corrosion experience, it is well known that, to protect metals under conditions brought about by stagnant water, highly excessive inhibitor concentrations must be used. Such conditions often dictate the use of cathodic protection for corrosion prevention.

It has always been an accepted fact that, where flow rates are low, dead

to the reaction products of corrosion was suggested by the author at the AWWA Indiana Section meeting in 1959. At the 1959 AWWA Annual Conference at San Francisco, it was shown that velocity (rate of flow) affects tuberculation (Fig. 2). Baylis,¹¹ in 1953, also showed the effect of velocity. McCauley⁸ gives strong weight to this factor. Eliassen and others,¹² in 1956, related corrosion rate to velocity for a water with a negative saturation index. They indicated that the increasing velocity decreased the path

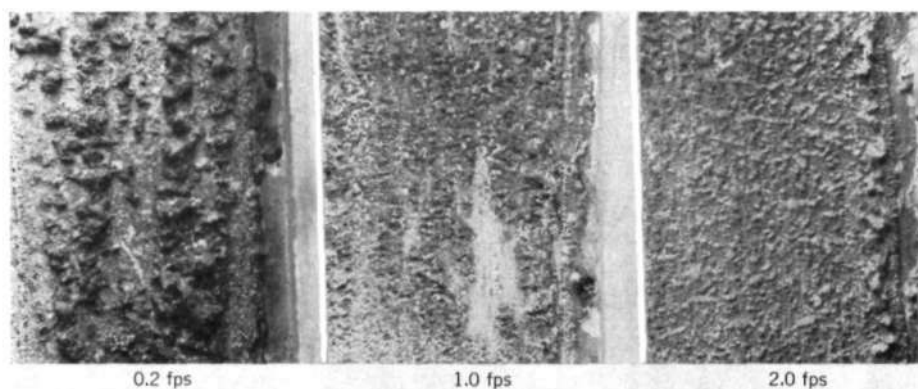


Fig. 2. Effect of Velocity on Tuberculation

The test was made with the use of Champaign-Urbana tap water at the velocities shown beneath each photograph. The corrosion rate after 120 days was 1 mg/sq dm/day.

ends are often the most troublesome areas in distribution systems, with regard to tuberculation, red water, and, often, tastes and odors. The reasons for the difficulty are the long time of contact that causes the accumulation of iron resulting from corrosion and the fact that the protective ingredients in the water are not made to act at the point of corrosion and on the surface of the metal.

The concept of employing mechanical means to bring the protective ingredients to the pipe surface and thus

of diffusion of oxygen through the laminar flow layer adjacent to the pipe wall. The oxygen in this non-protective water thereby accelerated corrosion.

The thickness of the laminar layer also limits the rate of diffusion of ions to the pipe surface. For a water with sufficient protective characteristics, the effect of oxygen can be nullified, or even be made to contribute to the *protective* action, when the thickness of the laminar layer is reduced. This thickness () is related to velocity

$(V)^{1/3}$ and arbitrarily to the friction factor (f) by:

$$\frac{V\delta}{\nu} = \frac{32.8}{\sqrt{f}}$$

and therefore, in turn, related to the Reynolds number, $\frac{VD}{\nu}$ (Fig. 3). D is the diameter; ν , the viscosity. Be-

turbulent pipe flows is usually considered to be between the limits for perfectly smooth pipe and limiting velocities beyond which there is complete turbulence—that is, no change in friction factor. The Hazen-Williams C has been plotted in Fig. 3 for a velocity of 4 fps, but there is very little difference in the position of the curves at other velocities.¹⁴

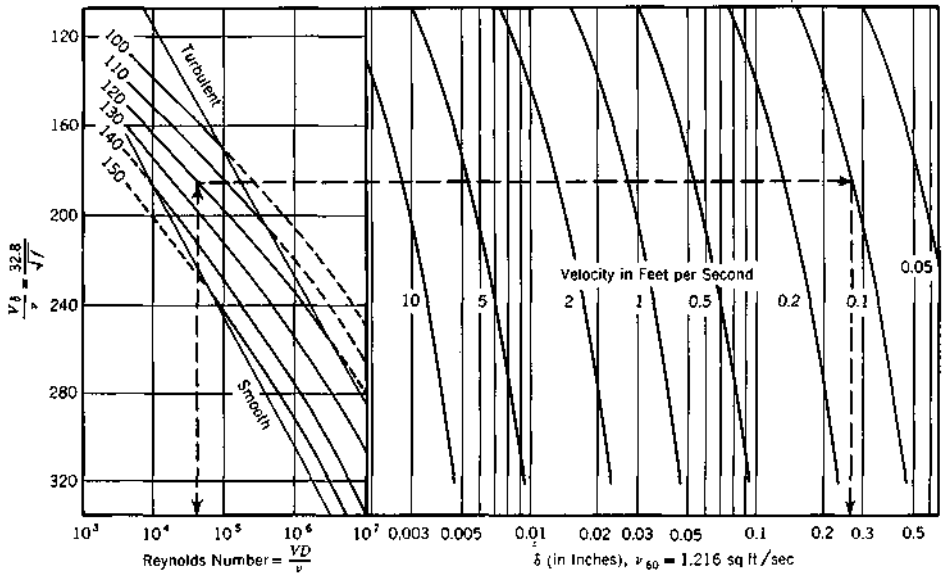


Fig. 3. Relationship of Laminar Flow Layer Thickness, Friction, and Reynolds Number

The values on the curves in the left portion of the figure represent the Hazen-Williams coefficient. The thickness of the laminar flow layer is greater for smooth pipe than for rough pipe. This diffusion is decreased by approximately half as the velocity is doubled.

cause the Hazen-Williams coefficient, C , is normally used by water utility investigators to establish roughness of pipe and is determined from the same measurements of velocity and head loss, the relationship between the Reynolds number and the Hazen-Williams coefficient is introduced to indicate the laminar thickness at various velocities. In water supply practice, the range of

It will be noted that the velocity of flow plays an important role with regard to the thickness of the laminar flow layer, which is decreased by approximately half as the velocity is doubled. It will also be noted that this thickness is greater for smooth pipe than for rough pipe. For instance, with a C coefficient of 145 for the example indicated in Fig. 3, the thickness would

be approximately 0.32 in., which indicates the greater need for higher velocities at new installations. This, in part, may explain discrepancies in observed tuberculation at various locations in the same community.

Figure 3 does not show the effect of temperature. Temperature affects the viscosity (ν), which, in turn, may increase the thickness of the laminar layer by approximately 30 per cent as the temperature decreases to 35° F.

A recent JOURNAL article¹⁵ gives an example of corrosion inhibition by the combined application of calcium carbonate stability and velocity. In the instance described, a community had suffered from red-water problems for nearly 25 years. The system was designed for fire flows greater than 500 gpm, but the demand was approximately 500 gpd. The *maximum* demand velocity in the residential area was about 0.04 fps in 6-in. pipe, which is a flow rate in the laminar range of the Reynolds number. Induced circulation at 60 gpm helped alleviate the distribution system problem, but data showed that corrosion continued until pH adjustment to a -t-0.3 saturation index eliminated the problem. When the induced velocity was reduced to 30 gpm (0.4-0.9 fps), a saturation index of approximately +0.6 was necessary to avoid corrosion by this water, which was softened by ion exchange and had a 90-ppm hardness.

Other Variables

It was mentioned earlier that much remains to be learned about the chemistry and mechanics for the prevention of corrosion. At the present time, essentially nothing is known about the effect of silicates, polyphosphates, or

aluminates. Studies should also be made on the effects of detergents, tannins, and organic color as influenced by specific qualities of water and flow characteristics. Until the effects of these factors are known, further advances in corrosion prevention will be limited.

Conclusions

It should be recognized that calcium carbonate stability must be classified as an adjunct to natural or artificial protective coatings on metals. This is true because the quantity of available protective ingredient is limited for any water and may not be sufficient to neutralize or react with the quantity of products resulting from corrosion—that is, the rate of reaction of inhibiting agents may not equal or exceed the rate of production of corrosion products from an unprotected metal. It is also clear that higher velocities of flow, even if induced by the aid of applied energy, improve the efficiency of calcium carbonate stability by bringing the protective ingredients more rapidly and in greater volume (or mass) to the point of corrosion reaction.

The saturation index can indicate the quantity of available supersaturation of calcium carbonate. But there is also a need for a numerical parameter that can indicate, more effectively than the saturation index, the latent buffer capacity of water to yield more available calcium carbonate by reaction with the OH⁻ corrosion product. Other aids or inhibitors may also be beneficial under certain conditions. These aids should be studied and reported *only* for specific test conditions or applications.

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