1946

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Roy Rankin
Fort Hays State University

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FORT HAYS KANSAS STATE COLLEGE STUDIES

GENERAL SERIES NUMBER TEN

SCIENCE SERIES No. 2

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By ROY RANKIN
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PRINTED BY
FERD VOILAND, JR., STATE PRINTER
TOPEKA, KANSAS
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21-1738

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FORT HAYS KANSAS STATE COLLEGE BULLETIN

VOLUME XXXV NUMBER 20

Entered as second-class matter July 28, 1921, at the post office at Hays, Kansas, under the act of August 24, 1912. Acceptance for mailing at special rates of postage provided for in section 1103, act of October 3, 1917. Authorized August 8, 1921.

Municipal Water Softening in Kansas

This study was made for the benefit of the more than one-half million residents of Kansas who live in cities and towns of the state and do not enjoy the advantage of soft water. Many of these persons are unaware that it is possible and practical to partially soften municipal water at little cost. In some instances an actual saving may be made by softening the water, as will be explained presently.

At the beginning, let it be understood by the reader that, though the writer is a teacher of chemistry, there need be no fear of encountering numerous chemical and technical terms that have little meaning for those untrained in the use of technical words. If found necessary to use technical expressions, they will be explained the first time they are used.

In order to the better qualify himself for the preparation of this paper, the author recently has made a personal study of the water supply systems of all the cities and towns of the state listed by the Division of Sanitation of the State Board of Health as operating water-softening plants. Seven of these places use well water exclusively. They are: Clyde, Hanover, Hoisington, Lincoln, Manhattan, Pittsburg and Wichita. Three cities use both well water and surface water. Beloit and Topeka use well water to reduce the turbidity of the river water before treating it. Erie uses well water to supplement the river water, large quantities of which are used untreated by an industrial plant located there. Lawrence has under consideration the use of well water to lower the turbidity of the river water. Cities which purposely soften surface water only are: Chanute, Cherryvale, Coffeyville, Eldorado, Emporia, Fredonia, Iola, Lawrence, Neodesha, Osawatomie, Ottawa, Russell and Washington. Eldorado softens its water only when it is necessary to pump water from the river to supplement the supply of soft water usually obtained from an artificial lake.

All communities using surface water are required to purify it and, in most cases, clarify it. Some of these unintentionally remove a part of the hardness of the untreated water. This is due to the fact that lime is used in the clarification process. Lime also tends to remove a part of the hardness, so that clarification and partial softening are accomplished in the same operation. Several of the municipalities using surface water could soften their water to a point where it is reasonably soft with little or no added expense. Why they do not do so is one of the unsolved riddles of city government.

In addition to the twenty-three cities and towns previously mentioned, there are 320 others with public water supply using ground water and forty-three using surface water. A very few of these use both kinds of water. Of the 320 using ground water, 250 have water of sufficient hardness to warrant the installation and operation of water-softening systems. Of the forty-three using surface water, twenty should soften their water while it is being clarified and purified.

The cause of hardness in water is the presence in solution in the water of certain soluble salts of calcium and magnesium. These two metals are present in such well known insoluble substances as limestone and magnesia, respectively. When soap is added to hard water, the calcium and magnesium in solution in the water interact with the soap, producing an insoluble, gummy material that adheres to the things being washed and to the walls of the containing vessel.

There are two distinct kinds of hardness either or both of which may be present in water. One kind can be destroyed by heating the water. This results in the formation of fine solid particles which collect on the walls of the pipe or other vessel in the form of a fairly soft scale. This type of hardness was formerly called temporary hardness because it could be removed by the application of moderate heat. The term is still much used. However, this form of hardness is now frequently designated as carbonate hardness. The hardness that persists in water after heating is called permanent or noncarbonate hardness. It is scale forming only when the water is evaporated as by continued boiling. The scale formed under these conditions is very hard. This type of hardness can be removed only by chemical means or by distillation.

The amount of hardness in water is expressed in two ways. The old way, still much used, is in grains per gallon. The newer and more convenient way to express hardness is in parts per million. One grain per gallon is equivalent to 17.1 parts per million (p. p. m.) Water that has 100 p. p. m. of hardness has sufficient hardness causing minerals in it to form 100 pounds of limestone (or its equivalent) from one million pounds of the water. When hard water is softened, the fine material settling out is largely powdered limestone or chalk. The chemist and water plant operator call it calcium carbonate. This will help to make clear the meaning of the statement, "The water has a hardness of 100 p. p. m. in terms of calcium carbonate." For the sake of accuracy, it must be added that if magnesium is removed from hard water along with calcium, the limestone will be mixed with hydrated magnesia, called magnesium hydroxide. However, the hardness is universally expressed in terms of calcium carbonate even though the sludge formed by softening water may not be pure limestone.

The hardest water supplied to the inhabitants of any town in Kansas, according to records available, is that at Dexter. It contains 1,988 p. p. m of hardness. It is pumped from shallow wells.

It has already been stated that 250 municipalities using well water and 20 of those using surface water should soften the water. These 270 localities have water with a hardness of 200 or more parts per million. It is a matter of fairly close agreement that most municipalities having water with less than 200 p. p. m of hardness will not find it practical, economically, to soften the water at public expense, though some of them might do so. That would depend largely upon the nature of the hardness. On the other hand, many, if not all, of the 270 places having water with 200 p. p. m or more of hardness could, in all probability, effect a saving for the consumers by softening the public water supply down to 75 or 100 p. p. m.

It is difficult for the average user of water to believe that softening water at public expense very frequently results in an actual saving on the part of the one who pays the taxes and the plumbing repair and water bills. Let it be understood, insofar as soap is involved, some idea of the waste to be assigned to hardness in water can be obtained from the fact that one-tenth of a pound of soap is wasted for each part per million of hardness for 1,000 gallons of water. For a water from which 250 p. p. m of hardness are removed, the saving would be 25 pounds of soap for 1,000 gallons of water. It is conceded that a very small portion of the water used is completely broken with soap, yet the waste is still so great that, according to the best authorities, the continued use of hard water in a municipal supply is an economic loss. For purposes of illustration, consider three Kansas cities, one small, the other two large. At Clyde, according to the calculations of Mr. Paul Haney, chief engineer of the Division of Sanitation of the State Board of Health, the softening of the public water supply results in a saving in cost of soap of $9.60 per year for a family of five persons.

This does not include the saving in cost of fuel used in the water heater due to decrease in scale formation.

Neither does it include the saving in cost of plumbing repairs that can be credited to the softened water. In view of the fact that the average family of five in Clyde has an annual water bill of $8 it would appear that such a family is being paid $1.60 a year for the privilege of using softened water. At Clyde the hardness of the water is reduced from 274 p. p. m. to 63 p. p. m. At Topeka, where both well water and river water are used, it has been calculated that the saving in soap by a family of five is $9 per year. At Pittsburg, where the hardness is lowered from 288 p. p. m. to 79 p. p. m., the saving arising from the softening of the water, according to the statement of the water commissioner, amounts to $12 per year for a five-person family. The average monthly water bill for such a family in Pittsburg is 81 cents. In addition to having the water softened, an objectionable odor due to the presence of sulphur compounds in the raw water is entirely removed. The actual cost to the city of Pittsburg for the entire treatment is $17.80 per million gallons. It is by no means an unusual experience for communities that have tried public water softening, especially those using ground water, to discover that the procedure results in a marked saving for the taxpayer and consumer.

The advantages of soft water can be stated briefly as follows: There is a saving in cost of soap and other cleansing agents as well as in labor in washing and cleaning. There is an increase in the life of textiles which must be laundered frequently, hence a saving in expenditures for wearing apparel and household linens. There is a marked reduction of scale formation in water heaters and cooking utensils. This results in a saving of fuel and labor needed for descaling operations and repairs. It is generally agreed that soft water is better for cooking purposes than is hard water. Most industries, especially those employing steam power, require soft water.

It has been stated that carbonate hardness can be removed by heating the water. This is not, however, a practical method, as it is expensive and quickly coats the vessel in which the water is heated with a heavy scale, increasing fuel consumption. The practical method is to mix quicklime or hydrated lime with the water to be softened. Since fifty-six pounds of quicklime will soften as much water as seventy-four pounds of hydrated lime, assuming equal purity of the two materials, it is more economical to use quicklime. The initial price for hydrated lime is frequently higher than for quicklime and freight charges for the former will be greater than for the latter because of the difference in weight of materials used. In spite of the possible saving, several of the softening and clarifying plants in Kansas use hydrated lime. If quicklime is used, a hydrator is usually employed. The cost of the hydrator is soon erased by the consequent saving arising from the use of quicklime.

To remove noncarbonate hardness, soda ash, often referred to as "soda," is employed. Soda ash is the dehydrated form of washing soda, commonly sold at the grocery store and extensively used in the home for "breaking" the water used in the laundry. It is frequently a component of scouring powders, soap powders and hard water soaps. It can be used to remove carbonate hardness, but is much more costly than either form of lime and no more efficient, so is never used in commercial scale operations except as it is needed for the removal of noncarbonate hardness.

In clarifying surface water by means of lime, it is an almost universal practice to add some alum along with the lime. This forms a sticky coagulum which aids greatly in collecting the sediment and in clarifying the water. In softening ground water, alum is sometimes added in rather small quantities. It is presumed to increase the settling rate of the sediment formed by softening. Four of the seven towns in Kansas softening their ground water supply use alum. The other three do not. The addition of alum has a tendency to increase noncarbonate hardness. The use of alum also increases the amount of lime needed as lime and alum interact with one another.

As soon as hard water is thoroughly mixed with the softening agents and alum, if it is used, the water becomes cloudy and if allowed to remain at rest, or to move very slowly, the insoluble matter causing the cloudiness will in time settle out. Consequently, all of the early type water softening plants are equipped with very large settling basins. Various devices are employed to secure thorough mixing and to hasten settling. The removal of the sludge collecting on the bottom of the basins is a problem requiring much attention.

Water softened by lime alone will have much less mineral content than the hard water, so that if it is entirely evaporated, the solid left will be much less than that obtained from the same amount of hard water. Water softened by the use of soda ash, or by the zeolite method, in which common salt is the material consumed, will contain a greater amount of mineral matter than the untreated water. Why this is true is not readily understood by those not familiar with chemical terms. Let it suffice to say that the new minerals formed in the water by the action of soda ash or of salt do not impart the quality of hardness to the water. Nor do the newly formed minerals tend to render the water any less fit for use, except in the case where the water before treating contains a high salt content along with much noncarbonate hardness.

Zeolite water softeners are found in some private homes and in many laundries and industries using steam boilers. Various trade names have been given to this type of water softener, but they all employ the same principle. The zeolite "sand" may be a natural or a synthetic material. No cloudiness is imparted to the water softened by zeolite, so no settling basins or filters are needed. Both kinds of hardness may be completely removed by zeolite, making the water as soft as distilled water, yet containing a greater weight of minerals than before softening. In view of the low cost of salt used to regenerate the zeolite and the small amount of equipment needed, it might appear that the zeolite method is the best one for softening water. That is undoubtedly true when water of zero hardness is required. Such water is seldom needed except for boiler feed and in some industries. Many industrial plants take municipally softened water and treat it with zeolite to adapt it to their needs. In many homes where publicly supplied softened water is not available, zeolite softeners are found. Many families cannot afford them and those who do, find that considerable attention is essential in order to see that a new supply of salt is added at just the right time and that the zeolite is properly washed after regeneration. There are no municipally operated zeolite water softeners in Kansas and a comparatively small number anywhere in this country.

Reverting now to the use of lime or lime and soda for water softening, consumers often ask how water can be softened with lime when *lime* causes hardness in water. The confusion arises from the incorrect use of terms. It is not lime that causes hardness in water, but rather certain soluble compounds of calcium or magnesium, previously mentioned. In some waters, soluble compounds of iron are also present. They do not add much hardness to the water, ordinarily, but they cause staining of fixtures and fabrics and are very objectionable for this reason. When lime is added to water possessing carbonate hardness, it interacts with the soluble compounds of calcium and magnesium which cause the carbonate hardness, forming insoluble compounds of these elements, which cloud the water and are eventually removed from it. The so-called *lime* left in the tea kettle and in the hot water pipe is not lime, but, in large part, a form of limestone, possibly mixed with magnesium hydroxide.

It may now be stated that noncarbonate hardness is caused by soluble compounds of calcium and magnesium, which are not decomposed by moderate heat. For the greater part, these are sulphates and chlorides of the metals named, rather than the bicarbonates found in water of carbonate hardness. To remove the metallic radicals from these heat-proof compounds, the best material is soda ash. It interacts with the soluble compounds to form insoluble ones. Strangely enough, the insoluble compounds are the same as those formed by the action of lime added to water of carbonate hardness. Since soda ash costs considerably more than lime, the practice is to remove more of the carbonate hardness, permitting some or all of the noncarbonate hardness to remain. The water used in the city of Hays may be taken as an illustration. Hays water averages 281 p. p. m. of carbonate hardness and has a noncarbonate hardness of 43 p. p. m. If 250 p. p. m. of the carbonate hardness were removed with lime, leaving the noncarbonate hardness unchanged, the total hardness remaining would be 76 p. p. m. This would be found highly satisfactory and no soda ash would be required. About sixty percent of the cities and towns in Kansas that supply water with a hardness greater than 200 p. p. m. fall into this class. The other forty percent would find it necessary to use some soda ash. A few of them would have to use a fairly large amount. Nevertheless, it is the usual experience that softening the water down to 100 p. p. m. or under, results in an ultimate saving for the consumer.

In addition to soluble compounds of calcium and magnesium, some Kansas waters contain soluble compounds of iron, occasionally accompanied by soluble manganese compounds. While it is true that iron compounds add slightly to the hardness of water, the amounts in which they occur are usually so small that the hardness caused by them is insignificant. However, if iron compounds are present in amounts greater than .3 p. p. m., they are sure to cause annoyance in other ways. The presence of iron in water is indicated by red stains imparted to kitchen sinks, laundry and toilet fixtures as well as by the unsightly appearance of white fabrics washed in such waters. In addition to this, very small quantities of iron compounds in water favor the growth of the so-called "iron bacteria." The growth of these bacteria commonly produces an unpleasant odor and taste in the water. Their growth frequently tends to obstruct the flow of water through the pipes. Iron compounds, if present in significant quantities in water that is being softened, may be removed easily in the same operation. The usual procedure is to oxidize the soluble iron compounds to insoluble ones by aerating the water. The water may be sprayed into the air or it may be allowed to flow from perforated horizontal pipes. In another method, the water flows in thin layers over baffles. Combinations of these methods are often employed. In all cases, the water after or during aeration flows over trays of coke. Much of the insoluble iron product thus formed is caught by the coke which must be stirred and scrubbed at intervals. The solids not caught by the coke are carried along by the water and are removed along with the insoluble calcium and magnesium compounds by sedimentation and filtering.

If manganese compounds accompany compounds of iron, they are removed in much the same way as iron compounds and in the same operation. In rare cases, manganese compounds are found difficult to remove and require special treatment for their removal.

Some waters contain so much carbon dioxide (carbonic acid gas) that the water is mildly acidic and attacks the water pipes. This immediately puts iron into the water and may eventually cause leaks in the pipes. Carbon dioxide can be destroyed by the addition of lime, but in most instances it is cheaper to remove most of the carbon dioxide by aeration. Aeration is also employed for the removal of gases having unpleasant odors. At Pittsburg, a special method of aeration is used for this purpose. The wells are 1,400 feet deep and the water is brought to the surface by means of "air lift" pumps. By this means, air is forced into the water near the bottom of the well under considerable pressure and its absorption by the water is rapid and its oxidizing power increased. Gases not oxidized by the air escape from the water as the air escapes at the surface where the pressure is released. Such systems can be used only in very deep wells.

Now that the advantages of water softening have been stated and some of the principles involved explained, it is in order to point out and discuss the various steps employed.

The first step, aeration, already discussed, is in many cases omitted. Frequently the first step is that of mixing the chemicals with the water to be treated. The chemicals are automatically measured as they are fed by machines into the incoming stream of water. Thorough mixing is absolutely essential. This is accomplished in various ways. Sometimes rapid mixing devices followed by a slow one in which paddles agitate the water to which the chemicals have been added are used. In some plants, compressed air or carbon dioxide is bubbled up from the bottom of tanks where the mixing is being done. In other plants, the water and chemicals flow over and under many baffles in a long channel. In one plant in the state, the incoming water enters an upright cylindrical tank at a tangent with the walls, so that a great whirlpool with a vortex in the center is produced. In all of these methods, the chemicals are introduced at the surface of the water. Newer mixing methods are now available. In these, the water and the chemicals enter at the bottom of a large upright tank which must be some twelve or fifteen feet deep. In this type of mixer, the sludge formed by the interaction of the chemicals reacting with the minerals causing the hardness is formed at the bottom of the tank and soon begins to collect there. Consequently, the chemicals are introduced into the sludge. This sludge is gently agitated, either by the incoming stream of water or by mechanical paddles. The result is that the softening operation takes place on the surface of the sludge particles so that they increase greatly in size and are unable to rise to the surface of the water some distance above. The resulting almost clear water overflows at the top of the tank into a trough which carries it away. The heaviest sludge particles collect at the bottom of the tank and are drawn off either continuously or at short intervals. As a result, the amount of sludge remaining near the bottom of the tank is practically constant. This type of mixer and clarifier is new, having come on the market shortly before 1940. Some have been installed since that date, most of them for military camps and war production sites. Only one is operating in Kansas at this time. It is at Chanute and is used to assist in softening the very turbid water pumped from the Neosho river. Plants of this type require no large settling basins like those used in the older type of softening plant, so occupy much less space and are cheaper to install. The time required for the treatment of the water is greatly shortened. The new system is especially recommended for the softening of ground water, but may be used in connection with the clarification and softening of surface water when the turbidity is not too high.

In the older type of softening plant, the water passing from the mixing chamber runs to a large basin sometimes called the slow mixing chamber. The more common name for this basin is the flocculator. The purpose of the flocculator is to more completely mix the chemicals with the water and at the same time to increase the size of the sediment particles in order that they will settle more rapidly when the water passes to the main settling basin. Horizontal, slowly rotating paddles slightly agitate the water. The motion of the paddles must not be rapid enough to break up the sediment particles, known as floc. Very little sludge is allowed to collect in this basin, but provision must be made for the removal of the little that does fall to the bottom of the basin.

The water passes from the flocculator to the main settling basin, the largest basin in the system. Frequently there are two settling basins, both large. Here the water moves very slowly and the solids settle to the bottom in the form of a mudlike sludge. In the smaller plants, the sludge is allowed to collect for several months. This necessitates deep basins. At intervals, the basin is drained and the sludge washed out with a fire hose. The larger plants employ a different system. Large scrapers move slowly along the floor of the basin, carrying the sludge to a trough at the end of the basin. The sludge is flushed out from this trough at frequent intervals, the time depending upon the amount of sludge formed. The scrapers are attached to an endless chain, one-half the blades traveling inverted in the direction opposite to the blades on the bottom of the basin. In another type of basin, the basin is circular in shape and the scraping blades rotate in a horizontal plane around a central shaft. The blades are equipped with vanes which gradually move the sludge toward the center where it collects in a hopper and is run off by flushing with a small amount of water. This type of basin need be drained only for repairs. The flocculator and settling basins, because of their great size, are usually not covered. This sometimes leads to difficulty from ice formation, occasionally causing damage to the walls of the basins.

The sludge from the settling basins may be allowed to dry in shallow pools from which it is carted away. At Ottawa, the sludge is used to fill in low land, subject to overflow, around the plant. In cases where a stream is near and no use is found for the sludge, it is run into the stream. In one place in the state, Pittsburg, the sludge is nearly pure limestone and still has some chemical value, so a part of it is recirculated to aid in settling the new and finer sludge. The sludge formed by softening well water in which only carbonate hardness is removed is fairly pure limestone and is suitable for reconversion into lime. There is located in the southern United States an industrial plant which requires a very large amount of soft water, five million gallons being softened daily. The sludge from this plant is such a pure grade of limestone that it is dried and burned in a lime kiln. Because the water contains considerable carbon dioxide in addition to the carbonate hardness, the amount of lime produced is more than twice that needed for softening the water. The plant, as a consequence, buys no lime for softening its water, but, on the contrary, has the additional lime for use in other plant operations. This is an interesting case in which a manufacturing concern makes a double saving by softening its water supply. A sludge cannot be used for the manufacture of lime if any magnesium is removed from the water.

After water has stood for variable lengths of time in the settling basins, it must receive further treatment. Water which has been softened by means of lime is very likely to be highly alkaline and, furthermore, may in time throw down more sediment. This difficulty is cared for in some systems by passing sufficient carbon dioxide through the water to reduce the alkalinity to a satisfactory degree. This operation is spoken of as recarbonation. In all cases in which it is necessary to add lime in excess, recarbonation is likely to result in a slight cloudiness in the water, owing to the formation of more limestone. This cloudiness may be in part removed in a small settling basin, but is commonly removed by the filter. Recarbonation is frequently spoken of as stabilization of the water. Twenty of the places in the state that soften their water recarbonate it, three do not.

The carbon dioxide used for recarbonation is commonly made by burning natural gas. Coke or fuel oil can be used where natural gas is not available. In some places, where the steam engines or diesel motors are used for power, flue gases from the boilers or exhaust gases from the motors are used as sources of carbon dioxide. This procedure supplies the necessary carbon dioxide without cost. If fuel must be burned to supply carbon dioxide, the heat produced can be used advantageously to heat water for the lime slaker. Hot water is much better for slaking lime than is cold water.

In some plants where the treated water is not highly alkaline, but some limestone is still carried in solution in the water, further precipitation of the limestone is prevented by the addition of complex sodium phosphates, sold under the trade name of calgon, nalco, etc. Nine cities in the State are using such commercial stabilizers in the softened water. This method of stabilizing softened water is relatively new. A few places use both recarbonation and phosphate treatment. It is doubtful whether that is actually necessary.

Water from the settling basin or that treated with carbon dioxide or phosphates goes next to the filters. At present all Kansas municipal softening plants are using rapid sand filters of the gravity type. This type of filter requires relatively small tanks with drain pipes in the bottom. These pipes are covered with very coarse gravel or cobble stones. A finer gravel lies above this coarse gravel layer. Next is a layer of sand. Such a filter effectively removes all traces of remaining sediment from the water. Provision is made for rapidly forcing water backwards through the filter bed to wash out the sediment when the filter becomes clogged. This wash water overflows into troughs set in the walls of the filter basin and flows to the sewer. Filter basins do not occupy much space so are always covered. They should be protected from dirt and the windows and doors of the room should be closely screened to keep out insects. Water from the filters goes directly into the mains or into storage reservoirs.

Most water softening plants are equipped with covered clear wells, sometimes located under the building and grounds of the plant. A few places store the treated water in large open reservoirs. This is not recommended. Adequate storage facilities should always be provided whether the water is softened or not.

When this study was begun, it was thought perhaps a comparison of the efficiency of the plants studied could be made. It became evident early in the study that this was not feasible. In the first place, the number of Kansas communities softening their water, especially those softening ground water, is too small to afford any adequate basis of comparison. Again, while most municipalities keep adequate records, some have almost none. This, in itself, is a strong indication of inefficiency. Some cities having adequate records include operating costs with chemical costs. Others separate them. This makes fair comparisons difficult, if not impossible. Furthermore, there are so many variable factors involved that it is frequently impossible to assign an apparent lack of efficiency to any one factor. Probably no system is more efficient than the person who operates it. From the experience of softening systems in other states, the writer is led to believe that in so far as the softening of ground water is involved, the greatest lack of efficiency originates in the method of mixing the chemicals with the water to be softened. For ground water at least, where there is little or no turbidity in the raw water, there is sound reason to believe that the newer, upward flow type of mixer is considerably more efficient than the older types. It has already been pointed out that the upward flow type of mixer requires no settling basin nor flocculator. This results in a great saving in the initial cost of the softening system. The time required for the passage of water through the new type of equipment is much shorter than in the settling basin type. This greatly reduces operating costs. There is also evidence that the effectiveness of chemicals used is greater in the new type of equipment. The writer has been informed by a number of engineers that they are including the upward flow type of mixer in plans being drawn for water softening plants to be built as soon as materials again become available.

In cities using surface water, there is some doubt as to the wisdom of using the upward flow type of mixer on account of the very great variation in the turbidity and in the hardness of the water. However, a goodly number of localities in other states are using this type of mixer, using it as a clarifier and in some cases both as a clarifier and softener. Communities using river water and contemplating the addtion of softening plants would do well to study the plants in operation in other states. Cities using surface water which has opportunity to lose most of its turbidity from long standing in artificial lakes should be able to use the upward flow type of plant to good advantage.

The question that will be uppermost in the minds of many readers will be, "What will it cost to install a water softening system?" That is a question that can be answered only for each individual community after all the facts are known. The size and type of plant are factors in the cost. Again, the size and type are dependent upon the quantity of water to be softened as well as on the amount and kind of hardness. Let it be borne in mind that in many instances there is an actual saving to the consumer by having the water softened, whatever the cost. Even if there is no ultimate saving, except in the few places where the hardness is excessively high, the advantage and convenience of soft water are worth all they cost.

21-1738