Pure water, as instanced by the symbol $\text{H}_2\text{O}$ rarely, if ever, occurs in nature; it is exceedingly doubtful whether anyone has seen or handled chemically pure water. Water drawn from wells, rivers, bores and other sources invariably contains a considerable amount of impurities, the nature of which depends largely upon regional conditions. The nearest approach to chemically pure water is rain water, but even this is affected by its environs. It absorbs gases from the atmosphere through which it is carried, and when it falls it picks up further impurities by decomposing and dissolving rocks, clay, chalk, and other earths, so that finally it becomes highly charged with gases and salts that vary according to the nature of the locality.

The common impurities occurring in most water supplies are bi-carbonate of lime and magnesia, and other matter in solution, matter in pseudo solution, suspended matter, decayed vegetable matter, and many other foreign substances, most of which are objectionable, and sometimes harmful.

The use of water in large quantities enters into almost every communal and industrial sphere, and its qualities are able to exert a beneficial or detrimental influence on many carefully-planned and delicate processes; consequently it is important that inherent disabilities be removed from the water before it is applied to its many uses, such as for wool scouring, washing, dyeing and bleaching in woollen and cotton mills, laundries, and for boiler feed purposes. Hard water should be softened, suspended matter and matter in solution and gases should be eliminated, and organisms should be destroyed.

The methods commonly used for the purification of water are softening by the lime and soda and by the base exchange processes, sedimentation and filtration for the removal of suspended matter, aeration and filtration for the removal of iron and vegetable matter, and degassers are employed for removing the harmful or corrosive gases.

It is not the purpose of this paper to explore the whole realm of water treatment in its many phases and applications, but rather our aim is to review the practical side of water softening by the lime and soda process, and then to review in passing the practical application of the base exchange method of water softening, where water of zero hardness is desired.
The softening of water for boiler feed is one of the more important cases for consideration. It is safe to say that the necessity for softening hard water for boiler feed is universally recognised, but it is not generally accepted that water containing as low as four or five degrees of hardness is unsatisfactory. It is a fact, however, that water containing five degrees of hardness can, under certain conditions, deposit scale \( \frac{1}{2} \) inch thick on boiler surfaces in less than twelve months. If this class of water is continually used for boiler feed, it is evaporated away, and the amount of hardness it contains is precipitated and deposited on the heating surface in increasing quantities.

The following substances are often found in boiler feed water:

*Scale Formers.*—Carbonate of Lime, Carbonate of Magnesia, and Sulphate of Lime. These salts, when present in boiler feed water in any quantity, readily form scale by precipitation under the temperature and pressure conditions in the boiler. The following substances, viz., chlorides of calcium, sodium and magnesium, sulphates of magnesium and sodium, also nitrates of calcium, sodium and magnesium, owing to their solubility, do not freely form scale themselves, but they can be precipitated under the high pressures and temperatures prevailing in modern boilers, and thus assist in the formation of scale, and promote corrosion of boiler plates. Taking magnesium chloride as a case in point—if a solution of this salt is boiled under a pressure of four atmospheres, hydrochloric acid is given off, and magnesium hydrate is precipitated. The former causes corrosion, and the latter forms scale. The synthesis of boiler scale is a complex process, and there is very little definite information available on the subject. It has been found that if an electric current is passed through a jar of water, bicarbonate and sulphate ions are attracted to the anode, whilst calcium and magnesium ions are attracted to the cathode. Thus bi-carbonate and sulphate ions are termed anions and magnesium ions and calcium ions are termed cations. All of these particles have the same electric charge, and the mutual repulsion thus produced keeps the particles in suspension, and the addition of an electrolite of opposite charge will neutralise the ions and cause precipitation. Cases have been known when one of the ions have been removed, and other ion will form a new salt by hydrolysis, as indicated by a change in the acidity or alkalinity of the water, as the case may be. Any change in Ph. value, of course, must be accompanied by a rearrangement of the ions.

When a bi-carbonate water is introduced into a boiler, a decomposing process takes place. Carbon dioxide is driven off by the temperature conditions, resulting in a change from
bi-carbonate ion to carbonate ion, and an increase in hydroxyl ion concentration. Calcium carbide or magnesium hydroxide, or both, will be precipitated. On the other hand, if the boiler water contains in solution matter that does not decompose, like bi-carbonates, the constant evaporation of the water must increase the concentration until the point of supersaturation is reached, and then the excess solute will be precipitated. Both of these conditions provide the essentials for scale formation.

The mechanics of scale formation are obscure, but it safely can be said that the transfer of heat through metal to water crystallises the various particles of scale-forming substances and brings about their deposition in the tube wall or shell plate as the case may be. The greater the heat transfer, the more the scale formation is accelerated, although the character of the scale formed on boiler surfaces is not of the same composition over the whole affected areas. Some scale-forming salts increase in solubility with increasing temperatures, consequently these are deposited on the cooler portions of the boiler, while other salts decrease in solubility with increasing temperatures, and are deposited on the hotter parts of the boiler. The formation of steam bubbles along tube walls, etc., no doubt influences scale deposition, for it is logical to conclude that the formation of a steam bubble is accompanied by an increase in the temperature of the iron over the area covered by the bubble, owing to the insulating tendency of the steam or gas. This overheating probably crystallises particles of scale around the edge of the bubble ring, and then, after the bubble is released and passes into the steam space, the overheated iron again comes into contact with the water, and further crystallising of scale particles occurs. We are more familiar with the effects of boiler scale than we are with the precise details of its occurrence.

A film of scale on boiler heating surface causes overheating of the metal; this increases the rate of scale formation, and the overheating is thus aggravated until failure of the metal occurs. The safe maximum working temperature for average low carbon boiler tubes and plates is 900° F. or thereabouts. Scale retards the flow of heat from the metal to the water, but the input to the metal is continuous, and its temperature rises, and its tensile strength is greatly reduced, with the result that the metal fails to withstand the stresses set up by the pressure conditions in the boiler. Such a failure involves the risk of a major boiler failure, the seriousness of which cannot be overstated.

The heat transfer in the hotter parts of a modern watertube boiler reaches the rate of approximately 90,000 B.T.U.'s per square foot per hour. At such high rates, a deposit of scale .05 inch thick would cause tube failures by overheating.
The tendency is to increase boiler pressures and ratings. Twenty-five years ago 150 lbs. per square inch was considered adequate, now 600 lbs. per square inch is not uncommon, whilst there are some installations operating at 1400 lbs. working pressure per square inch. Such high working pressures decrease the allowable margin of elevation in the tube temperature, consequently the problem of scale prevention becomes of greater importance as boiler pressures and ratings increase.

Recent research by R. E. Hall and others has been made into the relationship of the composition of the boiler water to the formation of hard calcium sulphate, and it has been found that if the carbonate—sulphate ratio is maintained above certain limits, the water, on evaporation, becomes saturated with calcium carbonate, instead of calcium sulphate, and the carbonate compound is thrown out of solution as a sludge, which can be removed by blowing down. If these conditions are maintained, then sufficient caustic soda is formed to similarly precipitate magnesium salts as magnesium hydroxide, which also can be removed by blowing down.

The easiest method of maintaining the desired ratio is by the addition of soda ash. Under the conditions that obtain in a boiler, soda ash decomposes and forms caustic soda, which reacts with the magnesium salts as mentioned previously. An excess of caustic soda, however, will cause caustic embrittlement and corrosion, therefore careful control of the soda ash application is essential. The extent of the decomposition of soda ash depends upon the temperature and pressure conditions of the boiler, and the control of the application of soda ash can only be achieved by regular analysis of the boiler water. Under steady working conditions, regular analysis and adjustment of the dosage and blowing down systematically will keep the boiler free from the deposition of hard scale.

There are three well-known methods of treating boiler feed water for the removal of hardening and scale-forming salts. These are:—

1. Precipitation and removal by the lime and soda process before the water enters the boiler.
2. Exchange of sodium salts for calcium magnesium bases by the base exchange softening process.
3. Precipitation within the boiler and insulation against scale formation by boiler compounds.

When water is softened by the lime and soda process, the soluble scale-forming salts are rendered insoluble by the application of lime and soda ash, and are precipitated as a sludge in a settling chamber provided for this purpose. The chemical...
reactions of the lime and soda process are given by the following:

Removal of Temporary Hardness Due to Bi-carbonate of Lime and Magnesia.

\[
\text{Ca}(\text{HCO}_3)_2 + \text{CaO} = 2\text{CaCO}_3 + \text{H}_2\text{O} \\
\text{(Soluble)} \quad \text{(Insoluble)}
\]

\[
\text{Mg}(\text{HCO}_3)_2 + \text{CaO} = \text{Mg(OH)}_2 + \text{CaCO}_3 \\
\text{(Soluble)} \quad \text{(Insoluble)} \quad \text{(Insoluble)}
\]

Removal of Permanent Hardness Due to Sulphates and Chloride of Lime and Magnesia.

\[
\text{CaSO}_4 + \text{Na}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{Na}_2\text{SO}_4 \\
\text{(Soluble)} \quad \text{(Insoluble)} \quad \text{(Soluble)}
\]

\[
\text{CaCl}_2 + \text{Na}_2\text{CO}_3 = \text{CaCO}_3 + 2\text{NaCl} \\
\text{(Soluble)} \quad \text{(Insoluble)} \quad \text{(Soluble)}
\]

\[
\text{MgCl}_2 + \text{Na}_2\text{CO}_3 + \text{Ca(OH)}_2 = \text{Mg(OH)}_2 + \text{CaCO}_3 + 2\text{NaCl} \\
\text{(Soluble)} \quad \text{(Insoluble)} \quad \text{(Insoluble)} \quad \text{(Soluble)}
\]

\[
\text{MgSO}_4 + \text{Na}_2\text{CO}_3 + \text{Ca(OH)}_2 = \text{Mg(OH)}_2 + \text{CaCO}_3 + \text{Na}_2\text{SO}_4 \\
\text{(Insoluble)} \quad \text{(Insoluble)} \quad \text{(Soluble)}
\]

It will be observed, from the above, that bi-carbonate of lime, calcium sulphate and other salts are precipitated as calcium carbonate. This is somewhat soluble (approximately 30 parts per million). Magnesium hydrate is also slightly soluble, but not to the same extent as the former. Because of this slight solubility, it is not possible to entirely eliminate hardness from water by the lime and soda process—there is always a slight residual hardness, but where it is desired that this should be removed, it can be eliminated with ease, and zero hardness water can be obtained by following the lime and soda treatment by treatment in a base exchange water softener.

The following table gives the amount of chemicals in lbs. required to treat 1000 gallons of water for each grain per gallon of hardening salt:

<table>
<thead>
<tr>
<th>Salt</th>
<th>Chemicals in Lbs. Required per 1000 Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90%\text{CaO} 95%\text{Na}_2\text{CO}_3 96%\text{NaCl} 63%\text{Ba(OH)}_2</td>
</tr>
<tr>
<td></td>
<td>lbs.</td>
</tr>
<tr>
<td>carbon dioxide</td>
<td>0.20</td>
</tr>
<tr>
<td>sulphuric acid</td>
<td>0.91</td>
</tr>
<tr>
<td>calcium carbonate</td>
<td>0.09</td>
</tr>
<tr>
<td>calcium sulphate</td>
<td>—</td>
</tr>
<tr>
<td>calcium chloride</td>
<td>—</td>
</tr>
<tr>
<td>magnesium carbonate</td>
<td>0.216</td>
</tr>
<tr>
<td>magnesium sulphate</td>
<td>0.073</td>
</tr>
<tr>
<td>magnesium chloride</td>
<td>0.093</td>
</tr>
<tr>
<td>sodium sulphate</td>
<td>—</td>
</tr>
</tbody>
</table>
For example, if the raw water contains eight grains of calcium carbonate and four grains of calcium chloride per gallon, the amount of chemicals to soften this water would be 0.72 lbs. of lime and 0.632 lbs. of soda ash per 1000 gallons of water treated. These weights are obtained by multiplying the lime factor 0.09 by eight grains for calcium carbonate, and the soda ash factor 0.158 by four grains for calcium chloride.

It is about 70 years since Dr. Clarke invented the process of treating water with lime for the removal of bi-carbonate of lime and magnesia, and a little later a process for removing sulphates of lime and magnesia was evolved. These early plants were very crude and limited in output, notwithstanding the large settling tanks and recirculating systems employed. From the days of these pioneers to the present day there has been constant research and experiments, which have resulted in many improvements in mechanical design of lime and soda softeners. Improvements in the process, method of application and accuracy of dosage, etc., have made possible and practical the large modern units, treating several million gallons of water per day.

During the process of water softening for the removal of carbonate of lime and magnesia by the addition of lime, the water becomes turbid owing to the formation of finely-divided particles of magnesium hydrate and calcium carbonate, and these must be removed by some means before a staple and properly-softened water can be assured. Formerly this turbidity eliminated by simple settlement only, which generally involved long settling periods, particularly so in instances where the water contained large amounts of magnesium. Under these conditions completion of the process was a matter for speculation, and after-precipitation very often gave rise to many difficulties.

The introduction of coagulents has greatly reduced the time required for settlement. It has accelerated the throwing down of the magnesium and calcium particles in a heavy sludge that settles at the bottom of the sedimentation chamber, from where it is freely discharged at convenient intervals. Sulphate of alumina is commonly used for coagulation, and when this is added to the raw water with the lime and soda ash, it forms a precipitate which adheres to the particles of solids, and, as coagulation progresses, large flocks are thus formed which readily fall to the floor of the settling chamber. The coagulum also has a capacity for removing colour from the water. Incidental to accelerating precipitation, coagulation also greatly assists in the complete removal of the insoluble salts, and reduces the time required for settlement and sedimentation, thus rendering the occurrence of after-precipitation less liable. More
recently sodium aluminate has been used as a coagulant with considerable success by water works engineers overseas, and it is claimed authoritatively increased efficiency and greater output from a given size of plant are obtained by its use, particularly in the case of magnesia-impregnated water. The cost of sodium aluminate is somewhat greater than that of sulphate of alumina, and its use results in a slight increase in the total cost of the overall treatment.

A well-designed lime and soda softener should be automatic in the application of the reagents. The amount of chemicals required varies with any variation in the flow of the raw water. Therefore, the proportioning gear should be actuated by the raw water, and at all times should be in direct proportion to the amount of raw water passing through the unit. Any increase or decrease in the amount of raw water automatically should result in a corresponding increase or decrease in the amount of chemicals added, otherwise partial softening only will be achieved, due to an insufficient amount of reagents being applied to the water, or alternatively the cost of treatment will be increased by unnecessary chemical consumption, and brought about by excessive dosage.

It reduces running costs if the incoming raw water is utilised to provide the power for driving the agitators in the chemical solution tanks, and also the stirring paddles for mixing the chemical solutions with the raw water. The apparatus for measuring the chemicals should be away from direct contact with these. Lime is notorious for “making up”; its fine particles adhere to the walls of tanks and measuring buckets, and if these are used for measuring the dosage, the proportion of chemicals added to the water will vary considerably and reduce the efficiency of the plant. The method of measuring and applying the chemicals is perhaps the most important factor in the design of a lime and soda softener.

It is very important that intimacy of contact be provided for the chemical solutions and the raw water. To ensure this, mechanical mixing and agitation is essential. Reference has been made to the difficulty of softening water that is high in magnesia content, owing to the difficulty of precipitating the magnesium hydrate, and it will therefore be obvious that ample provision should be made for settlement and sedimentation. Not less than three hours’ settling capacity should be provided, and if possible the flow of the settled water should be in an upward direction at a rate not exceeding six feet per hour, preferably three or four feet rise should be provided, and the settled water should be filtered through some form of a filter before leaving the softener. Ordinarily a wood wool filter is provided, with
WATER TREATMENT IN INDUSTRY.

good results. This should have a filtering depth of three feet, and the medium is usually packed between perforated plates secured to the shell of the main tank. It is perhaps worth mention that a cylindrical tank gives a more even flow, and has less dead spaces, than a rectangular one. Also a circular tank is stronger, and requires no stiffeners or stays. The sludge thrown down by precipitation can be removed in various ways. In some units it is removed by ordinary sludge eductor pipes at the floor of the settling chamber, and in others a revolving sludge gear, manually operated, is employed for sludge removal. The most effective method of dealing with sludge is to make the floor of the settling chamber an inverted cone, and at the lowest extremity incorporate a sludge discharge valve. With this arrangement the sludge is effectively removed, and a minimum amount of water is lost.

Summarised briefly, a lime and soda water treatment plant should incorporate the following:—

(a) The plant should be automatic.
(b) Mechanical mixing is essential.
(c) Not less than three hours’ settling should be provided.
(d) The effluent should be filtered.
(e) Provision should be made for sludge removal.

One of the best-known lime and soda softeners may be taken to typify the mechanical details of a well-designed plant. The softener is a single unit plant, the general outline being a large cylindrical tank surmounted by a covered-in platform, upon which the dosing and measuring gear can be mounted if desired. The raw water is discharged through a float-controlled valve into a hard-water box, whence it flows through a sliding valve or penstock on to the blades of a water wheel, and passes on from the water-wheel chamber into the down take, which is an open-ended cylinder arranged concentrically with the main tank. The water wheel is rotated by the incoming water, and is the prime mover for driving the chemical solution agitators and the mixing paddles. Its spindle is extended over the down-take and solution tank, and the agitators, which are attached to vertical spindles, are actuated by a bevel gear drive from the water-wheel shaft. The chemical dosage is regulated by the amount of raw water entering the plant. A small amount of the raw water is by-passed, and delivered into a proportioning box, from where it is delivered into a dividing box, which delivers an exact proportion through a sliding port into a regulating tank, so that this tank is filled by the flow of a definite amount of water. In the regulating tank are float chambers, and a float in each chamber operates the dosing gear for each chemical to be applied. In
each chemical solution tank there is a dip pipe or weir, which is attached to a float in the regulating tank by a flexible wire running in grooved pulleys, so that, as the regulating tank is filled by the incoming raw water, so the dip pipes are lowered in the solution tanks, and the chemical solutions are delivered into the down-take with the raw water. The solutions are thoroughly mixed with the raw water by a series of six or eight rotary paddles in the down-take. These are mounted on a vertical shaft, and are spaced alternately with fixed baffles attached to the shell of the down-take. The mixing arrangement is similar to that adopted by Joule for his classical water-stirring experiment for the determination of the rate of exchange between B.T.U. and foot pound. The down-take terminates at a point about six feet above the floor of the settling chamber, and is bell-mounted, so that the chemically-dosed water is evenly diffused into settling chambers, where it rises vertically toward a wood wool filter at the top of the softener. The filtering area of the wood wool filter is equal to the cross sectional of the softener main tank, less the area of the down-take, which is approximately two feet in diameter. The rate of filtration is very low; it is approximately 40 gallons per square foot per hour. Such a filter will give years of efficient service with very little attention, but in passing it might be observed that inadequate settling would bring about the reverse of this.

The dimensions of the softener are determined by the settling period provided for, and the rate of rise desired for the settled water. For a plant of 3000 gallons per hour capacity, with four hours’ settling capacity, and a vertical rise of four feet per hour, the main tank would be 13 feet 6 inches diameter by 24 feet high.

The more modern plants now have the chemical proportioning gear at ground level. The proportioning agent is the raw water, as before, but, having the regulating tank and solution tanks at ground, better supervision of the process is possible. Also, the later plants have separate measuring appliances for each of the chemicals used, so that the chemical ratios can be varied to meet any change in the characteristics of the raw water. Sometimes, instead of the dip pipe and float arrangement, pumps are employed for adding the chemical solution to the raw water. The raw water is measured by a special meter, which makes an electrical contact after every so many gallons are measured. This actuates a motor and sets the chemical pumps in action, each pump delivering a charge of chemical solution into the raw water. The pumps are controlled by a time switch on the motor, and the amount of solution added can be controlled with ease.
WATER TREATMENT IN INDUSTRY.

In considering the cost of lime and soda treatment for boiler feed, it is desirable that some further note be made of what happens if treatment is not provided. The use of hard water for boiler feed leads to the formation of scale, and scale leads to burnt-out tubes, blistered plates, prolonged and frequent cleaning of boilers, and a soaring coal bill, whilst corrosion provides tube failures and other troubles, that generally occur at a time when they are most inconvenient. There are times when a steam plant is called upon to carry large overloads for long periods, and when continuity of service is essential, but these are the conditions under which disabilities due to hard feed water reach a climax, and put the plant out of operation at a critical stage, involving loss and inconvenience. With a boiler plant evaporating 30,000 lbs. of steam per hour from 100% feed make-up, having a hardness content of 16.3 grains per gallon, there will be a substantial reduction in the cost of fuel if the water is softened.

Assuming that the mineral analysis of this water is—

<table>
<thead>
<tr>
<th>Mineral</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium bi-carbonate</td>
<td>12.2</td>
</tr>
<tr>
<td>Magnesium bi-carbonate</td>
<td>6.4</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>1.2</td>
</tr>
<tr>
<td>Magnesium chloride</td>
<td>3.2</td>
</tr>
</tbody>
</table>

and that the plant is working 24 hours per day, 300 days per year, the approximate cost of a lime and soda plant capable of dealing with 3000 gallons of water per hour would be £1550. The running costs would be—

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment charges</td>
<td>124 0 0</td>
</tr>
<tr>
<td>Depreciation charges</td>
<td>46 0 0</td>
</tr>
<tr>
<td>77.5 tons of lime</td>
<td>387 0 0</td>
</tr>
<tr>
<td>27 tons of soda ash</td>
<td>378 0 0</td>
</tr>
<tr>
<td>8.3 tons of sulphate of alumina</td>
<td>132 0 0</td>
</tr>
<tr>
<td>Two operators, two hours per day</td>
<td>120 0 0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>50 0 0</td>
</tr>
</tbody>
</table>

The boiler evaporates 30,000 lbs. of steam per hour over the period covered by the costs given above, and if 75% efficiency is allowed for a mechanically-fired boiler with superheater, the amount of fuel required would be 11,847 tons, costing £14,808, and therefore the combined cost of fuel and feed water softening is £16,045/16/- annually.

The feed water under review has 16.3 degrees of hardness—(this is not abnormal, as many waters contain more than 40 degrees)—and under the temperature and pressure, lime and magnesia would be precipitated in the boiler at the rate of about
seven lbs. per hour, or 168 lbs. per 24 hours. If it is conceded that 80% of these are removed by regular blowing down, there still would remain a sufficient quantity to produce scale \( \frac{1}{4} \) inch thick in a short time. This amount of scale would be capable of reducing the boiler efficiency considerably. Certainly there would be a loss of 6% to 10% in boiler efficiency owing to the presence of the insulating film of scale on the heating surface.

The resistance to heat of carbonate of lime is eighteen times greater than that of iron, and the resistance of sulphate of lime is fifty times greater, so when there is a film of these substances interposed between two heat-transferring agents the transmission is retarded, and much heat is lost. In the case of a boiler, the hot gases flow over the outer surface of the tubes and plates, but is unable to respond to the laws of heat transmission because the film of scale opposes the transfer of heat from the hot gas to the water. Consequently, the gases pass through the boiler, and are exhausted to the chimney at a temperature much higher than would be the case if the boiler surface in contact with the gas was free of scale, and thus efficiency is lost, and the cost of fuel is increased.

Without softening the feed water, the efficiency of the boiler referred to previously would fall from 75% to 67%—a loss of 8%—and the amount of fuel required for the same output of the boiler would increase from 11,847 tons to 13,262 tons, at a cost of £16,577, an increase of £532 over the combined cost of fuel and water treatment. This shows that a water softener, when applied to a very average hard boiler feed, is capable of saving £532 annually in fuel, quite apart from savings obtained from reduced maintenance charges on boiler, stoker, and furnace, etc.

Sometimes boiler compounds are employed to overcome the difficulties incidental to the use of hard water for boiler feed. One variety depends upon linseed oil forming a film over the surfaces of the particles of calcium and magnesium, and so prohibit the formation of scale by preventing the particles from cementing together in a hard scale. Other compounds use sodium carbonate and various other alkali to precipitate the salts in the boiler. Boiler compounds do not reduce the concentration in the boiler, but, to the contrary, they increase it; therefore, as the concentration in the boiler should be kept at a minimum, the use of compounds should be avoided. At the best they can be termed only an expedient or makeshift. There is no method of correctly proportioning compounds in correct ratio to boiler feed. They are generally introduced into the boiler in a haphazard way, and, unless the greatest care is exercised, the result is likely to be inadequate or excessive dosing, which leads on one hand to scale formation, and on the other to excessive deposits.
in the boiler, which may cause caustic alkalinity by the decom-
position of soda ash under the pressure and temperature
conditions prevailing. With a water softener, the correct ratio
of chemicals to water is maintained, and can be adjusted before
the treated water enters the boiler, and the precipitation takes
place outside the boiler, so that the concentration of salts in the
boiler is kept within safe limits.

It has been stated previously that the lime and soda method
of water softening cannot entirely eliminate hardness owing to
the slight solubility of the calcium carbonate and magnesium
hydrate precipitate, and, as it is sometimes desirable, if not
imperative, to have zero hardness water, the base exchange method
of water softening is employed, either in conjunction with the
lime and soda process, or singly. When a large amount of water
that is high in mineral content is required to be reduced to
zero hardness, the dual method of treatment is generally
employed. The water first is treated in a lime and soda softener,
which reduces the hardness to four or five degrees, and this is
followed by treatment in a base exchange plant, which reduces
the hardness to zero. There are several reasons for the adoption
of the dual treatment. In the first place, the reduction in
hardness brought about by the lime and soda treatment repre-
sents the total elimination from the water of salts in direct
proportion with the reduction in hardness. If the hardness of
water is reduced by 20 degrees, it means that the equivalent of
20 grains of calcium carbonate is entirely removed from each
gallon of water so treated. The lime treatment also has the
advantage of being lower in first cost, and also in running costs.
An instance of this is given by the following figures:

To remove 20 degrees of hardness from 100,000 gallons of
water, 353 lbs. of lime are required. To regenerate a zeolite
softener, after the same duty, approximately 1000 lbs. of salt
would be necessary. The cost of lime and salt are about equal,
and, since a specific duty can be performed with less lime than
salt, the general practice is to remove the bulk of the hardness
by lime treatment, and follow this by base exchange treatment
for the removal of the hardness left by the lime treatment. As
stated previously, the dual process is especially advantageous
when the water is fairly high in hardness.

In a base exchange water softener the hard water is passed
through a bed of zeolite. This material has the capacity for
exchanging sodium for carbonate and other salts of lime, with
the result that lime and magnesia are by this exchange entirely
removed from the water.

Bi-carbonate of lime is converted to sodium bi-carbonate.
Bi-carbonate of magnesia is converted to sodium bi-carbonate.
Calcium sulphate is converted to sodium sulphate.
Magnesium sulphate is converted to sodium sulphate.
Calcium chloride is converted to sodium chloride.
Magnesium chloride is converted to sodium chloride.
And the bi-carbonates, sulphates and chlorides are taken up by the zeolite, and this exchange is continued until the exchange capacity of the zeolite has been reached. A zeolite softener is generally designed to deal with so many gallons of water of specific character between regenerations, and the material should never be overrun to such an extent as to diminish the exchange capacity. Regeneration should be provided for at convenient intervals, that will ensure a zero hardness effluent at all times. The zeolite is restored to its original exchange capacity by saturating it with a brine solution of common salt. The brine dissociates the calcium and magnesium from the zeolite, which takes up sodium from the brine, while the brine takes up the calcium and magnesium chlorides of these bases. Generally, natural zeolite is employed as the softening agent in base exchange softeners. Natural zeolite is obtained by refining and stabilising glauconite—a characteristic material of the green sand marls found in considerable deposits in many parts of the world. The bulk of the world’s supply of natural zeolite is produced in Canada and the United States of America.

Extensive deposits of glauconite sand and clay exist in this country, and analyses have shown that some of these carry up to 53% of glauconite, and there is at least one company engaged upon the refining and stabilising of the local raw material. The local finished product compares favourably with the best Canadian and American material, both as regards exchange capacity and durability. One method of treating glauconite to ensure that the granules preserve their size, and be as little subject to disintegration as possible under the attrition set up by back washing, regeneration, etc., is to treat the glauconite granules with an alkali silicate, and follow this with an acid reacting solution. It is necessary to clean the glauconite prior to treatment, by washing with a salt solution, using the same solution repeatedly, so that, though the water may be hard at the commencement, it becomes softened and more effective by the repeated washings. The washing is continued until all the fine and disintegrable substances are removed. Glauconite thus treated is harder, and has a higher exchange capacity than ordinary glauconite.

The base exchange water softener is a very simple apparatus, and generally consists of a steel or concrete tank fitted out with valves for controlling the flow of raw and soft water, also flushing and brining. The zeolite bed is usually three to four feet
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deep, and is supported on a bed of graded gravel about twelve inches deep. A strainer system is arranged at the base of the tank to provide an even down draught of the water through the bed of softening material. The collector or strainer consists of cast iron header, with laterals along each side; the laterals are fitted with phosphor bronze nozzles, screwed in at suitable pitches, through which the water is drawn into the pipe system. The collector or straining system is usually cast in concrete or cement, with only the phosphor bronze nozzles exposed to the water, in order to avoid any electrolytic action of the brine. The raw hard water is delivered into the softener at the top, and is strained down through the zeolite, and as soft water is drawn off through the strainer system. The water can be delivered under pressure, this being one of the advantages of the base exchange method of water softening. Water treated by this method does not require repumping, and the hydraulic head lost through the plant is insignificant. The regenerating brine is prepared in a brine tank arranged conveniently to the softener tank, and it is introduced into the softener by an ordinary steam-operated injector or by simple pumping.

The time required for regenerating natural zeolite is about 20 to 25 minutes, using a 10% brine solution. This time will vary according to circumstances, but if the zeolite bed is loosened and regraded by a reversal of flow immediately before regeneration, and an intimate contact is provided for the brine with the whole of the softening medium, this time should not be exceeded. On the other hand, if the bed is packed and a weak solution is used, the time for completion of the regeneration process may take as long as 45 minutes, or even longer. Regeneration should be regular, and the softener should not be allowed to overrun its exchange capacity, over-exhaustion of the zeolite reduces the exchange capacity, and besides, hard water gets into processes where it is unexpected, and so causes damage and delays. The desirability of regular control for zeolite softeners has led to the recent development of a mechanical control whereby the softener can be flushed, brined, rinsed, and returned to service automatically. This control employs a special meter, which makes an electrical contact after every so many thousand gallons of water are registered. The motor driving the control mechanism is actuated by the contact, and a time switch measures the flushing, brining and rinsing periods. The special central multiport control valve enables the unit to be brought into line for any of the regeneration functions. The time switch also controls the brine pump motor, so that the correct amount of brine is introduced automatically when required.

Zero hardness water or no hardness water has a real and practical value wherever water is required for washing and
cleaning purposes. It is a valuable asset in woollen mills, where large quantities of water are necessary for scouring, washing, bleaching, and dyeing, and also in silk and cotton mills, where much water is required for similar uses. Zero hardness water is essential for the success of these operations. Hard water gives rise to insoluble soap curds, which impregnate the stands of the material with calcium and magnesium precipitates, and the result is very often the production of second or third rate goods from first quality raw materials.

In the laundry, zero hardness water improves the various cleaning processes, and keeps down costs by reduced soap bills compared with hard water. It has been proved that with water five degrees of hardness 8/4 lbs. of soap are wasted for every thousand gallons, ten degrees of hardness wastes 17 lbs. of soap, and fifteen degrees wastes 25 1/2 lbs. of soap for every thousand gallons. By way of further illustration—a laundry uses 10,000 gallons of water containing ten degrees of hardness per day; the amount of soap wasted daily is 170 lbs., costing approximately 4d. per lb. This wastage would amount to more than £700 per annum, and more than 60% of this sum could be saved by the installation of a zero hardness softener, at a cost of approximately £360 to £400. Such an installation would practically recover its cost in the first year of operation.

When the lime and soda softened water is followed by the zeolite treatment, the water should be efficiently filtered before it passes through the zeolite section, and no after precipitation allowed to take place, otherwise the granules of zeolite would become coated with calcium carbonate, and rendered inactive. Water softened by the base exchange process should be delivered into the softener in a clean, clear condition, and the softener should not be used to filter out suspended matter and impurities that may be present. If the raw water carries suspended matter, it should be filtered before it is allowed to enter the softener, and the softening medium kept in a clean condition. If the zeolite is allowed to become impregnated with fine particles of clay, these adhere to the surface of the granules, and interfere with the exchange action by greatly reducing the contact area. More water is also required for washing, and it has to be applied at higher velocities in order to remove the foreign matter, resulting in loss of zeolite by the attrition set up by agitation incidental to expanding the zeolite bed to allow the impurities to be entrained and removed by the wash water; also there is increased risk of losing zeolite by carrying it away with the waste wash water. When efficient filtering is necessary, it is not wise to rely too much on the efficiency of a wood wool filter. In a straight out lime and soda plant the wood wool filter, with a
little attention, is quite satisfactory, but when the lime treatment is followed by the application of the base exchange process, it is advisable to use a sand filter to safeguard the zeolite against after precipitation and insulation.

Sand filtration is now regularly employed for the purification of water supplies for all purposes which require the following:—

(a) The removal of suspended matter.
(b) The elimination of colour.
(c) The elimination of odours and tastes.
(d) The removal of iron.
(e) The elimination of organic matter.

All of these can be accomplished regularly with a correctly-designed and efficiently-operated plant, which can be relied upon to remove up to 99.5% of bacteria from the water.

The value of water filtration obtrudes itself upon the primitive savage, who makes a hole in the sand of the river bank, into which he strains his water supply, and is recognised universally by engineers, manufacturers, laundymen, housewives, and others, wherever water is used.

The genesis of the modern filter is the slow sand filter, which was originated in England about the year 1830. In these filters the filtration rate commonly used is 3,000,000 gallons per acre per day, or three gallons per square foot per hour. The depth of the sand bed, when new, is three to four feet, and cleaning is performed by scraping off the soiled upper surface of the sand. When twelve inches to eighteen inches have been removed in this way, the beds are resanded to their original depth. Several processes are involved in sand filtration. First there is the straining out of the particles that are too large to pass through the interstices between the sand grains. This builds up a film of matter finer than the sand through which the water is strained, and then bacterial action produces a gelatinous film or coating in the grains of sand, to which adhere the most minute particles of matter in the water, in much the same way as dust is held by any sticky substance. This coating on the sand develops and fills up the spaces between the sand grains, so that, with maturity, the filter becomes increasingly efficient, and delivers an attractive or inviting effluent. A freshly-cleaned filter is not so effective as one carrying a good film, through which the water has to strain before it enters the collecting system below the sand and gravel. Mechanical cleaning of filter beds has been largely instrumental in the development of the modern rapid filter. It has made possible filtration rates fifty times greater than those employed in slow filtration. The high rates of rapid filtration do not allow time for the
development of a natural film on the sand grains, so an artificial film is produced mechanically by adding a small amount of sulphate of alumina or ferrous sulphate to the water. Water that is naturally alkaline will precipitate sulphate of alumina as aluminium hydrate—a jelly-like substance—and this forms a mat or film on the sand, and builds up a very efficient filtering medium. If the water is not naturally alkaline the desired degree of alkalinity for precipitation of the alum can be obtained by adding lime or soda ash to the water. The amount of chemicals required to produce a good artificial film on the sand varies from 0.4 grains to 7 grains per gallon for sulphate of alumina, or ferrous sulphate, and the lime or soda dosage is generally about half that of the alum.

After a period of service a filter bed becomes fouled and clogged by the accumulation of matter filtered out of the water, which builds up an excessive frictional resistance to the flow of water through the filter. This resistance is eliminated by cleaning the filter bed. There are various methods by which this can be done. Sometimes mechanical agitation of the sand by rotary rakes, accompanied by a reversal of the flow of water through the filter bed, is employed. The rakes loosen the accumulated matter and allow it to be readily entrained in the washing water, so that it is carried away with the waste wash water. Another method is reversal of flow only in what is termed high velocity wash, in which case the velocity of the wash water only is depended upon to expand and loosen the sand bed and carry away the accumulated matter with the wash water.

A third method of cleaning a soiled filter bed is to blow compressed air up through the sand to agitate the sand and loosen the soiling matter by scrubbing the sand grains against each other, then to follow this by an upward flow of wash water, which easily carries away all the matter loosened and thrown into suspension by the air scour. The combined air scour and wash is generally preferred to the other methods, although all three methods referred to are well and favourably known among waterworks engineers. The combined cleaning process undoubtedly reduces the percentage of water required for cleaning the filters; it prevents the formation of mud balls, and will keep the bed free from contraction, cracks, and irregular hydraulic grading. Rapid filters are constructed to work under pressure or gravity, depending upon operating conditions convenient to locality and other considerations, such as the uses for which the filtered water is required. The rates of filtration vary from 80 to 200 gallons per square foot of filter area per hour. The filter units can be constructed of steel or concrete, pressure units
being totally enclosed, while gravity units can be open to atmosphere. In a typical pressure filter the water enters at the top and flows downward, through the sand gravel, into straining system at the floor of the vessel or container. The coagulating chemicals are applied as a solution from chemical pots, or they can be applied in dry, powdered form from dry feeders. Where solution feed is applied, the chemical pots are connected to the high and low pressure zones of a venturi or orifice plate situated in the raw water pipe. This sets up a differential pressure across the chemical pot, and induces a flow of chemical into the raw water before it enters the filter. The chemical solution is super-saturated, and needle valves in the connecting pipes give ready adjustment of the dosage which can be controlled within close proximity of the desired amount.

In the case of dry chemical feed, the amount of chemical is fed from a hopper on to a rotating disc arranged concentrically within the hopper discharge port. As the disc rotates an adjustable blade scrapes off the outer edge of the base of a cone of chemical formed by the angle of repose of the chemical fed from the hopper on to the disc. This is delivered through a chute direct into the raw water or into a chemical mixing bowl, where it is mixed with water and injected into the raw water by chemical pumps. The filter bed consists of a bed of washed and graded waterworn quartz sand; the depth of sand ranging from 21 inches to 30 inches. The sand is supported upon layers of graded gravel, so graded that each layer supports the finer material above it. The gravel is graded from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch, and the depth ranges from 12 inches to 18 inches. The size of sand grains is, of course, a very important point. If the grains are too fine, the filter runs will be short, and beds clog more readily. Sand having an average size of 0.6 millimetres appears to be fairly satisfactory. It permits of reasonable filter runs, although it is well known that with sand of a given size the length of runs varies greatly for different conditions of water, and also with temperature differences. The method adopted for back washing is also a factor entering into sand grain sizes, as the wash water should be able to expand the sand bed 30% to 40%. The strainer or collector system consists of a cast iron header pipe, to which brass lateral pipes are secured at pitches of four to six inches. The lateral pipes have perforations that face the floor of the filter, and the free ends are plugged. The perforations are arranged so as to destroy any jet action of the incoming wash water. The functions of the strainer are to ensure an even down draught of the filtrate through the sand bed and to provide an even distribution of the wash water. To ensure efficiency in both of these functions definite ratios are to be observed with regard to the cross...
sectional area of the main header to the total area of the laterals, and again in the total area for flow provided by the perforations in the laterals. The air for agitating the sand is introduced and distributed in a separate distributing header and lateral system, similar to that used for the wash water, and arranged in the gravel immediately above the other.

When it is desired to clean the filter (generally when the frictional loss reaches 5 lbs.) air is blown up through the sand for three or four minutes. This loosens and throws into suspension all the accumulated matter. Then a combined air and wash is applied for about two minutes, after which the air is shut off, and water only applied for a further two or three minutes, until the waste wash looses its turbidity, thus indicating a clean filter.

A filter plant is essential for any textile works where the water supply is turbid or carries colour, iron or organic matter. Bleaching and dyeing and other processes, particularly where delicate shades of coloured fabric are concerned, require clean water.

Water purification by filtration is doing its share to improve the dairy products of this country. Butter factories, for obvious reasons, are situated in districts where the only water supply available is a more or less polluted stream or irrigation canal, but a filter will enable a choice grading of their product to be maintained by effectively purifying the water used for washing churns and butter. If dirty and contaminated water is used for these purposes, the quality of butter falls away, placing it in a second or third grade category, and involves a very considerable loss of revenue. A filter is also a valuable asset in the cordial and ice-making industries. A much-improved and a more attractive product is obtained from filtered water.

The purification of swimming pools, to render them immune from disease-carrying germs, is performed by filtration, which does away with the costly "empty and fill" method of keeping the contents of the pool clean and wholesome. The water is drawn off from the baths from one side or end by a circulating pump. A small amount of coagulating chemicals is added to the water to provide a film or mat on the filter bed. The water is delivered into the filters, where it is filtered and purified, and then returned back to the pool at the opposite side or end from where it was drawn off. An application of chlorine to the filtrate renders it perfectly sterile, and a slight residual chlorine is maintained in the pool at all times. The water is circulated
repeatedly, the whole contents of the pool being turned over once to four times per 24 hours, according to the bathing load.

A public swimming pool that is not equipped with a recirculating purification plant is a source of danger to public health. One infected swimmer can spread disease amongst hundreds of unsuspecting victims. On the other hand, filtration and sterilisation of the water renders the risk of infection from affected persons negligible, and provides a practical guardian of public health.
DISCUSSION

The President said the paper was of great interest to all those who had boilers under their care, or those connected with industries using large quantities of water. All would agree that the use of soda ash in boilers was a very objectionable practice, owing to the difficulty of control. The slide of a boiler tube, encrusted so as to have less than half its original bore, was a terrible example of the result of faulty boiler practice.

Mr. R. J. Bennie said the paper was a most valuable contribution to the Proceedings. It was a paper of record, and he hoped that there would be an opportunity for discussion after it had been circulated. He was very pleased to note that Australian glauconite was being worked up for the base-exchange plants, and was of such good composition. Regarding electrolysis between phosphor bronze nozzles and cast-iron headers, it might interest members to know that in recent tests on pipes buried in the ground it had been shown that where a copper service pipe was connected to an iron pipe, the latter became badly pitted near the junction, owing to the galvanic currents set up by the couple. But special insulating bushings of a bakelite composition had been inserted between the copper and iron, and had completely cured the trouble. He suggested that this procedure would be applicable to the case mentioned by the author. Concrete coverings had been shown to offer little or no protection to pipes from electrolysis. One phase of the water treatment question that he felt ought to be emphasised was the very great annual saving in water bills which might be made in many industries where the water, after simple treatment, could be reused.

Mr. F. C. Hall said that many cases had been brought to his attention where the oil in turbine bearings and the casings of high-speed steam engines had been caused to emulsify owing to the use of improper boiler compounds. A small amount of priming had carried over sufficient of the boiler compound to cause the trouble. In one case in the country, where tri-sodium-phosphate had been used as a coagulant for clay in the water, this had occurred. Considerable research was necessary to find softeners which would not cause this trouble. He thanked Mr. Gamble for his paper.

Mr. E. H. G. Morris said that it was extraordinary how few of the industries seemed to be aware of the advantages of water treatment. This was particularly noticeable in the textile industries, where the necessity for pure water was paramount.

Mr. Gamble, in reply, said the measures found to be effective in preventing galvanic action outlined by Mr. Bennie were very
interesting. The arrangement of bedding the collector and laterals of a water softener in concrete is not by any means ideal, as the concrete has to be broken to give access to any component part that may require attention. It would appear that bakelite bushings for the laterals, where they are fitted into the main header, would give a much better arrangement from every point of view. In regard to Mr. Bennie’s suggestion that trade waste water might be reclaimed profitably, this is being done regularly by users of large quantities of water overseas. The practicability or otherwise of treatment naturally depends upon the nature of the impurities. Generally, the reclaiming process calls for sedimentation, chemical treatment, precipitation, and filtration. As to Mr. Hall’s experience of impurities being carried over from the boiler and emulsifying the crank case oil of an engine, the use of tri-sodium phosphate no doubt was intended to prevent corrosion of boiler tubes and plates. Priming and surging can carry impurities over to the engine, and so give rise to the difficulties met with by Mr. Hall. There are recent cases on record where excessive use of tri-sodium phosphate has caused serious corrosion of the turbine blades. The corrosion can be prevented if the water is softened and the gas removed by de-aeration. The use of tri-sodium phosphate in the manner mentioned by Mr. Hall was an example of attacking the problem from the wrong end, and dealing with the effect rather than the cause. Softened water would keep down surging in the boiler. The steam would be clean and the oil would not become contaminated by contact with the steam in the manner referred to by Mr. Hall.

The discussion was adjourned.
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