A STUDY OF BOILER FEED-WATER TREATMENT AT
KANSAS STATE COLLEGE OF AGRICULTURE
AND APPLIED SCIENCE

by

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DISCUSSION OF BOILER FEED-WATER

The problem is to devise an improved method of treating the boiler feed-water used at the power plant at Kansas State College.

Raw or untreated water contains many impurities which cause difficulties when it is used in boilers. These difficulties are: scale formation, corrosion, embrittlement, foaming and priming.

Scale

The Permutit Company (1) defined scale as being the general term applied by engineers to mineral deposits left by waters in boilers, evaporators, condensers, water pipes and all wetted surfaces to which heat is applied. Its physical composition varies from a hard granite like substance, to soft crumbly chalk. Its color may be pure white, gray, brown, red or anything between those and black. Chemically, scale is for the most part composed of compounds of calcium and magnesium, with a wide range of impurities such as mud, iron, manganese, silicon, etc., in greater or less degree. Its main cause, however, is the hardness of the water.

The Dearborn Chemical Company (2) states that the impurities which cause scale formation are calcium sulphate,

calcium carbonate, magnesium carbonate, magnesium chloride, calcium nitrate, silica, oxides of iron and aluminum and suspended matter.

One of the losses caused by scale is the waste of heat due to the insulating effect of scale.

F. L. McCune (3) shows the following fuel losses with scale in boilers:

Thickness scale in inches	Per cent loss of fuel
3/64	9.55
1/16	12.75
1/8	22.95
1/4	41.31

S. T. Powell (4) summed up the major losses due to scale as follows:

1. Reduced efficiency due to insulating properties of the scale.

2. Economic loss due to boiler outages during cleaning periods.

3. Increased maintenance as a result of internal cleaning.

4. Depreciation of equipment occurring from scale formation and removal.

It is difficult to evaluate the effect of scale in boilers since there are many factors to be considered in establishing the specific losses in efficiency attributable to

this cause. That scale causes such losses requires no argument. Many writers, however, in their enthusiasm to present the subject forcibly, have exaggerated these losses. Scale is frequently held responsible for reduced boiler efficiency for which many other defects in operation are responsible.

Corrosion

The Dearborn Chemical Company (5) divides the contributing causes of corrosion into the following three groups: 1. The presence of dissolved oxygen in the boiler water. 2. The concentration of hydrogen ions or the presence of acids or acid forming salts. 3. Dissolved salts in the water causing galvanic action between dissimilar metals or dissimilar parts of the same metal, the latter being due to strain, temperature variations, or impurities.

Corrosion in boilers takes place in one or all of three ways, namely, general, pitting and grooving. General corrosion is the least dangerous, but the boiler must be watched closely lest it be gradually weakened to an unsafe degree. Pitting is readily detected as a rule and is frequently very difficult to stop without a thorough search after the causes. Grooving is often very hard to locate before leaks take place, since such corrosion takes place

where the metal has been bent or strained and is hidden
from any but the most careful inspection. General corrosion
of steam boilers may usually be traced to the water employed
but it is also caused by the action of certain boiler feed-
water compounds containing tannic acid, sulphate of copper,
etc. Copper sulphate reacts with the iron or steel, an
equivalent of iron passing into solution. Great caution
should be exercised in the use of such materials in boiler
practice. Where there is a corrosive action because of the
presence of acids in the water, or of oil containing fatty
acids which will decompose and cause pitting wherever the
sludge can find a lodging place, it may be overcome by the
neutralization of the water by carbonate of soda. This
should be carried to a point where the water will just turn
red litmus blue. As a prevention of such action, only the
highest grade hydrocarbon oils should be used. Acidity may
appear where salt water makes its appearance in a boiler,
as may occur in marine practice from leaky condenser tubes
or priming into the evaporators. This acidity is caused by
the hydrolysis of magnesium chloride giving hydrochloric
acid and magnesium oxide under high pressure. The acid in
contact with the metal forms an iron salt, which as soon as
formed, is neutralized by the free magnesia in the water,
thereby precipitating iron oxide and reforming magnesium
chloride. Where it is unavoidable that some salt water

should make its way into a boiler, the water should be
neutralized by milk of lime, which will convert the mag-
nesium chloride into magnesium hydrate and chloride of cal-
cium, neither of which will cause corrosion, but both of
which will cause scale.

Air sucked into the system by the feed pumps is a well
recognized cause of corrosion. Air bubbles form below the
water line and the oxygen of the air attacks the metal.
The rust thus formed is washed away by circulation or dis-
lodged by expansion, leaving a minute pit which serves for
a lodging place for other air bubbles, and in this way con-
tinues the action.

Both general corrosion and pitting may be reduced or
even eliminated by using an open feed-water heater thus ex-
pelling the air, or better still, a feed-water heater con-
nected to a vacuum pump.

Galvanic action takes place in certain instances. The
remedy for it is usually the installation of zinc plates
within the boiler, which must have positive metallic contact
with the metal of the boiler. The zinc plates are corroded
instead of the boiler, and the latter is protected at the
expense of the former. The positive contact necessary is
difficult to maintain, and the efficiency of such plates
is questionable except for short periods after their
installation.

Caustic Embrittlement

According to S. T. Powell (6) intercrystalline cracking
of boiler steel occuring while the boilers are in service
is termed embrittlement, or more generally, caustic em-
brittlement. The term is used to distinguish the phenomenon
from corrosion cracking due to stresses. Failures of this
nature are indicated by fine cracks in the metal which occur
always below the water line. The general characteristics
of metal which has become embrittled may be summarized
briefly as follows:

1. The cracks occur below the water line and appear to
start on the dry face of the joints.

2. The failures occur in rolled plates, cast steel or
steel boiler plate of good quality.

3. The cracking is irregular, and changes in direction
of the cracks are marked. The cracks do not join one
another.

4. The cracks occur at joints, that is, at the rivets
or at the lap joints, affecting both plates. They occur
also at butt joints in both straps and plates, usually at
points of greatest stress.

5. There is a marked brittleness of metal under shock;
static tests, however, do not indicate this phenomenon.

6. The brittleness of the metal appears generally to be localized at the areas adjacent of the joints.

7. Black iron oxide or sulphide is present at embrittled areas.

8. A partial return of ductility by heating or by removal of the boilers from service for a time.

No great number of boiler failures can be attributed to embrittlement. The failures have occurred, however, at sufficiently frequent intervals to attract marked attention, especially in certain sections of the country. During the past twenty-five years, no less than twenty cases of embrittlement of boiler metal have occurred in one section of the country. Many other failures of this kind have taken place elsewhere in stationary steam stations, in marine service and in locomotive boilers.

Two theories have been advanced to explain the cause of the trouble. It has been claimed by some investigators that the primary cause of embrittlement is the result of improper processing of the metal used or to stresses set up at localized points due to the method of fabrication of the boiler affected. It is claimed further that the concentration of the caustic soda in the water employed for boiler-feed use is not responsible for this phenomenon, since the concentration of this salts in boilers may not be

carried to a point where the metal could be so affected. Opposed to this view is the theory of caustic embrittlement. The advocates of this theory contend that the cause of embrittlement, as indicated by circumstantial evidence, is the absorption of hydrogen released by the decomposition of caustic soda, which action may take place at high temperature and pressures and in the absence of other salts, principally sulphates, or at least when these salts are present only in small amounts. The use of boiler compounds or the decomposition of excess sodium carbonate in an overheated boiler may account for the presence of the caustic alkali.

Walter Rosehain and D. Hansen (7) investigated several cases of cracked boiler plates similar to the embrittlement type and could find no general chemical or physical defects in the metal. The cracks were intercrystalline in nature. The investigators tried to develop similar cracks by prolonged stresses but were not successful. They suggest that this type of crack may be produced by stresses acting over a period of years. In their discussion they state that corrosion or chemical action may accelerate intercrystalline cracking, and point out that in the cases investigated corrosive influences had been at work, and may have accelerated the formation of the crack. No study was made of the water used.

R. S. Williams and V. O. Homerberg (8) studied inter-
crystalline fracture in steel, and concluded that the im-
purities are located around the grain boundaries and are
attacked by the action of hydrogen and hot caustic solution.
This action is accelerated by stress.

Cecil Desch (9) states that chemical action frequently
advances more rapidly along the surfaces which separate the
crystal grains than through the mass of the metal, and is
more likely to occur when the portion exposed to the reagent
is in a state of tension than when it is in an unstrained
condition. Strong acids are not selective. Passage of
gases into the metal appears to follow the boundaries and
the same may be said of weak electrolytes.

J. A. Jones (10) in investigating the failure of pans
used in evaporating nitrates found the cracks to be of the
embrittlement nature and was able to reproduce these cracks
by means of combining stress with the chemical action of
various nitrate solutions. In a limited number of cases,
he produced intercrystalline cracks by using potassium
hydroxide solution. He concluded that these cracks occur
only when the stress is above a certain value, and is com-
bined with chemical action.

G. E. Stromeyer (11) in summing up the cases of boiler
failures which have come to the attention in England, shows
that a large number of cases of embrittlement attributed to

other causes than caustic in water are now readily seen to
be due to caustic. He told of testing pieces of steel sub-
ject to tension in caustic evaporators and reported that
they became brittle in a few months. The concentration of
caustic solution was between 200 and 500 grams per liter.

Foaming and Priming

According to Allen Rogers (12) foaming and priming are
probably the least understood of boiler phenomena. Priming
may be defined as an ebullition so violent that water in the
form of spray is carried from the boiler before its
separation from the steam can take place. It is controlled
by the relations of heating surface, evaporation surface,
circulation, and working load, all of which are factors of
the violence and rapidity of the ebullition, and by such
features as dash plates, water space, all of which affect
the possibility of violently boiled water reaching the
steam exits. Priming, as thus defined, is a matter of
boiler design and operation.

Foaming is the formation of bubbles upon and above the
surface of the water. The less easily these bubbles break
the higher will the foam rise. It may become so excessive
that the bubbles, or films of water inclosing steam, pass
out with the steam. Naturally, priming, or a tendency to
prime, is an important factor in excessive foaming. Aside

from this, the difficulty with which the steam pushes
through the surface film of water and separates from it is
a controlling agency. With nearly pure water foaming is
very slight and never sufficient to cause the loss of water
with steam in a well-designed boiler. Nearly all impurities
dissolved or suspended in water increase the foaming ten-
dency, though no two substances may do so to the same degree.
As steam is used from the boiler the impurities are concen-
trated and finally a stage is reached which will cause ex-
cessive foaming. If, therefore, the quantity of impurities
and the effect of each were known, the calculation of the
foaming tendencies of a water would be a simple matter.
Unfortunately, our knowledge of this department of boiler
physics is very slight. It is practically impossible to
determine the quantity of suspended matter in a boiler at
any time. Suspended matter originally present in the water
is largely precipitated, while additional suspended matter
is derived from loosened scale and from the precipitation
of impurities in solution in the feed-water. Organic matter
holds a similar indefinite place in connection with foaming
calculations because a large but unknown proportion is pre-
cipitated. It is, however, usually present in relatively
small amounts in boiler waters. Although both of these
classes of substances are undoubtedly important, the effect
of precipitated magnesium being especially noteworthy,

their role in inducing foaming cannot, therefore, be calcu-
lated from an analysis of boiler feed-water. For this rea-
son and because all other dissolved substances are insignif-
icant in amount in a highly concentrated boiler water it is
generally customary to attribute foaming to sodium and po-
tassium salts. These substances are highly soluble and the-
ir relative importance in different waters is easily deter-
mined from analyses. The expression 2.7 Na + 2 K will re-
present these salts generally within 5 per cent an always
within 15 per cent. It will correspond very closely to the
"non-incrusting solids" usually estimated from hypothetical
combinations and is sufficiently accurate for practical use.
Since these compounds are at best a rough approximation of
the foaming tendency of a water, nothing would be gained by
the use of a more cumbersome expression from which they
could be more accurately expressed. The following formula
may, therefore, be adopted:

Foaming coefficient f = 62rNa + 78rK + 2.7 Na + 2K

It is hoped that investigations may lead to a better
understanding of this phenomenon and hence to a more re-
liable index to the foaming tendency of waters. The letter
"r" in connection with the symbol of a radical signifies
reacting value.

The steam engineer is interested more in the number of hours his boiler may be run under ordinary load without danger of foaming than in the coefficient given above. This is really a combined index of priming and foaming and may be calculated from the formula: Run in hours: $Rh = a/b$ $(c/f - 1)$ in which a equals water capacity of boiler, b equals hourly quantity of feed water used, f equals foaming coefficient, and c is a constant which represents in parts per million the concentration that will cause excessive foaming in the type of boiler under consideration.

The usual remedy for foaming is blowing off a portion of the highly impure water and replacing it with fresh feed-water. If a in the foregoing formula be made to represent the amount of water blown off at any time, the expression will indicate the length of time that may with safety elapse before blowing off again.

The following approximate values have been determined for the constant c for various types of boilers and are adapted from Christie's "Boiler Waters."

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Locomotive boiler ..................... 2,500 to 3,500
Stirling boiler ....................... 4,000 to 5,000
Modern water-tube boiler (Babcock
    and Wilcox or Heine) .............. 5,000 to 7,000
Horizontal return tubular boiler ..... 8,000 to 10,000
Old-style two-flue boiler ............       17,000
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From these figures it appears that the locomotive

boiler is the type most likely to give trouble on account
of foaming and offers, therefore, a satisfactory basis for
an arbitrary classification of waters according to their
foaming tendency. A non-foaming water may be defined as one
that can be used throughout one week's work without foaming;
a semifoaming as one that cannot be used so long as a week,
but one that will require one complete water change to avoid
foaming in a locomotive boiler not oftener than every two
days; and a foaming water as one that cannot be used so long
as two days in a locomotive boiler without blowing off or
changing water to prevent foaming. Accepting these con-
ditions, the approximate classification of water will result:

Non-foaming: f not greater than 60
Semifoaming: f greater than 60 but not greater than 200
Foaming   : f greater than 200

The objectives to be obtained in the treatment of water
for boiler use are:

1. The production of a water entirely or nearly free
from scale forming substances.

2. The elimination of gases and salts which cause
corrosion.

3. The securing of a water which has little or no
foaming and priming tendencies.

4. A water conditioned as to P H value so as not to
contribute to so called caustic embrittlement.

The proper treatment of water for softening usually accomplishes all of these objectives more or less perfectly.

The softening of public water supplies is accomplished by the addition of lime and sodium carbonate, followed by sedimentation, or filtration, or both, to remove the precipitates. Water may also be softened by the use of zeolites. Alum is sometimes added, as experience has shown it to be beneficial in clarifying the water, although the use of alum increases the non-carbonate hardness and, therefore, requires additional soda ash. The continuous recirculation of sludge which has been precipitated to the bottom to the coagulating basin or mechanical clarifier has been found to increase the efficiency of the floc formation, the floc is better crystalized, and the amount of chemicals required for precipitation is reduced. An excess of lime is sometimes added to waters high in non-carbonate hardness and magnesium salts, the excess being neutralized with soda ash.

The application of chemicals in water softening plants is now accomplished by: (1) the addition of saturated lime water, (2) the continuous feeding of a standard-strength solution of milk of lime and soda ash, (3) the continuous feeding of a standard solution of lime, (4) the addition of weighed amounts of lime at stated intervals of time, (5) the dry

feeding of hydrated lime, and (6) the dry feeding of ground quicklime through continuous slakers.

The hardness of all water supplies is due to four mineral compounds which they hold in solution:

Calcium bi-carbonate

Magnesium bi-carbonate

Calcium sulphate

Magnesium sulphate

Chlorides and nitrates of calcium and magnesium are also sometimes present. Softening consists in removing a part or all of these salts from the water.

Calcium and magnesium bi-carbonates were formerly designated as temporary hardness, but are now almost always called carbonate hardness. Calcium and magnesium sulfates were formerly designated as permanent hardness or incrustants, but are now almost always called non-carbonate hardness. Calcium and magnesium bi-carbonates are soluble. In order to remove calcium bi-carbonate from water in which it is present, it is necessary to convert it into the normal carbonate. The magnesium must be precipitated as the hydroxide because of the solubility of the carbonate. This may be done by driving out the carbonic acid by boiling or neutralizing the carbonic acid by lime. When lime is added to hard water, its action is two-fold; it neutralizes or
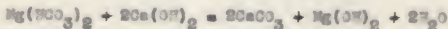
absorbs the free and half bound carbonic acid, thus form-
ing the normal carbonates and precipitates the magnesium
as the insoluble hydrate.

The alkalinity determination of raw water is usually
a measure of the carbonate hardness, but in softened water
and in some western waters, the alkalinity may also include
hydrates and carbonates of sodium and potassium; the latter
is readily apparent when the alkalinity exceeds the total
hardness.

The non-carbonate hardness is the difference between
the total hardness and the carbonate hardness, and requires
the addition of soda ash for its reduction or removal.

The chemistry of water softening is probably best ex-
plained by showing the chemical reactions that take place
when lime and soda ash are added to the water containing
calcium and magnesium salts.

1. Reactions that take place when lime is added to a
hard magnesium water are:

$$Ca(HCO_3)_2 + Ca(OH)_2 = 2Ca CO_3 + 2H_2O$$

$$Mg(HCO_3)_2 + 2Ca(OH)_2 = 2CaCO_3 + Mg(OH)_2 + 2H_2O$$

$$CO_2 + Ca(OH)_2 = Ca CO_3 + H_2O$$

$$Mg SO_4 + Ca (OH)_2 = Mg(OH)_2 + Ca SO_4$$

2. Reactions that take place when soda ash is added to a hard magnesium water are:

$$Ca\ SO_4 + Na_2\ CO_3 = Ca\ CO_3 + Na_2\ SO_4$$

$$Mg\ SO_4 + Na_2\ CO_3 = Mg\ CO_3 + Na_2\ SO_4$$

$$Mg\ CO_3 + Ca(OH)_2 = Ca\ CO_3 + Mg\ (OH)_2$$

Caustic soda may be used to remove both the carbonate and non-carbonate hardness from water; but when caustic soda is added to water containing calcium and magnesium salts, it precipitates the magnesium as insoluble magnesium hydroxide and absorbs the carbonic acid, resulting in the formation of an equivalent amount of sodium carbonate. If there is enough non-carbonate hardness in the water being treated to react with the sodium carbonate formed then caustic soda may be used as a softening reagent instead of lime and soda ash, but the lime and soda ash required to accomplish the same results at present prices cost less.

According to S. T. Powell (13) softening water by base-exchange silicates, termed zeolites, consists in passing the water through a bed of zeolitic material which possesses the property of removing the calcium and magnesium from the water and replacing these substances with sodium or potassium. The exchange takes place fairly rapidly so that the hard water in passing through the mineral may be com-

pletely or almost completely softened.

A zeolitic mineral will continue to soften water until nearly all of the sodium has been exhausted from it. When this condition results, the zeolite may be regenerated, that is, have the sodium which has been removed during the softening process, replaced. Regeneration is effected by treating the mineral with a strong solution of sodium chloride. The reverse action then takes place and the calcium and magnesium which have been extracted from the water by the zeolite pass back into the brine solution and the sodium is taken up by the mineral.

The term zeolite through common usage has been divorced from its original meaning. Zeolite as the word was used originally, indicated certain specific minerals, namely, a group of hydrous silicates. At the present time, this name is applied not only to these silicates but to a number of base exchange silicates which are artificially produced. There is a fairly large number of natural base-exchange substances. The chemical formulas of different minerals vary, but most of them are hydrous silicates of sodium and aluminum. The sodium being released is replaced by other bases forming new combinations. This permutation action is the distinguishing characteristic of all zeolites.

The equipment used in a zeolite water softener is similar to a pressure filter, although the process is funda-

mentally different from filtration. The base-exchange
mineral is contained in a steel tank. The mineral bed is
supported on a gravel bed beneath which is the under-draining
system. The softener is operated in the same way as a pres-
sure filter, the raw water enters the apparatus generally
at the top of the unit and the soft water is discharged from
the bottom. The salt or brine solution for regenerating
the zeolite is passed into the softener at the bottom of the
unit and is distributed through the bed by the underdraining
system. Practically all of the softeners sold at the
present time are operated under pressure.

The softeners are operated for a given period of time,
and at the end of the run one unit is cut out of service
and backwashed with clean water. This is done to remove any
suspended solids which may have collected on the surface of
the zeolite during operation.

After the washing has been completed, a strong sodium
chloride solution is run into the softener. The zeolite is
in contact with the salt solution for a time and is then
drained from the unit. The softener is washed with enough
clean water to flush out any excess of salt, and is then
ready for service again.

It is essential that water which is to be softened by
zeolite should be practically free from suspended solids.

For this reason it is customary to provide filters for the
clarification of turbid waters prior to softening. Sus-
pended solids coat over the grains of the softening material
thereby preventing the water from getting into direct con-
tact with the surface of the zeolite. Water high in iron or
manganese is objectionable.

PRESENT TREATMENT

The college at the present time secures water for
boiler feed purposes from wells located on the campus. This
water is pumped to a softening pit and treated with lime
and soda ash. The period of retention in this pit depends
upon the rate at which water is being used. This rate
varies from season to season. In the winter, steam is used
to heat the buildings upon the campus. Practically all of
this steam is returned to the boilers as condensate so there
is a relatively small amount of make up water used in the
boilers. In the summer, no steam is used for heating,
therefore the exhaust from the turbines is released to the
atmosphere. This necessitates the treatment of more raw
water to supply the boilers. Approximately 50,000 gal-
lons per day is treated in the summer and 30,000 gallons
in the winter.

The softening is performed intermittently in a large
pit. The amount of lime and soda ash required is added in

the dry form. Mixing is secured by agitation with com-
pressed air. The water is allowed to remain in the well
until needed and then it is drawn off at a point about
18 inches above the bottom of the pit. The reaction period
varies from one to three hours. Before going to the boilers
the water passes through an open feed-water heater which
operates with exhaust steam which heats the water to nearly
210 degrees Fahrenheit. Much of this heat is lost as the
water passes through an uninsulated surge tank before enter-
ing the boilers. The water thus delivered to the boilers
is incompletely softened and contains much colloidal matter
in suspension because of the insufficient time allowed for
the softening reaction to be completed and for the sedimen-
tation of the precipitate. There is no filtration to take
the place of thorough sedimentation.

The use of this water has caused a great deal of
trouble in the operation of the boilers. A great number of
tubes have been burned out making it necessary to replace
them. It has also been necessary to shut down the boilers
about once every two months to remove the scale from the
tubes.

PROPOSAL NO. 1

In this thesis three different possible plans are being
proposed. The first and simplest plan calls for the con-

struction of an additional softening pit similar to the one
now in use. This would allow a such longer time for the
chemical reactions and sedimentation thus giving a more
completely softened and clarified water.

The water in these wells would be treated alternatly
the one being treated while the other is being used. These
wells can be filled or drained in one hour. By making use
of the 25,300 gallons storage space now present, a period
of 16 hours can be allowed for sedimentation in each well
if 30,000 gallons of water are treated per day or 8 hours
if 60,000 gallons are treated.

PROPOSAL NO. 2

The second proposal is the installation of a continuous
automatic softener and filter instead of intermittent
softening in the two pits. As a rule, intermittent soften-
ers permit of a more accurate dosing with chemicals since
the entire calculated charge of the softening reagents is
added to the water at one time. It is not necessary to se-
cure complete sedimentation in the case of continuous
softeners because the filtration results in complete clari-
fication. Continuous softeners have the advantage of oc-
cupying less space as only one tank is required. They are
also more flexible in operation.

Continuous softeners may be used with either cold or

hot water. The first is called a cold process softener and
the second a hot process softener. The hot process has
several advantages over the cold process:

1. It acts as a combination feed-water heater and
softener in one apparatus.

2. It effects a reduction of the scale forming solids
to two grains per gallons or less.

3. There is less trouble from after deposits.

4. There is an elimination of the dissolved gases,
thereby reducing the corrosive properties of the water.

5. The apparatus required is smaller than that used
in the cold process on account of the rapid precipitation
of lime and magnesium salts at high temperature.

6. Hot process softeners may be installed frequently
within the boiler room, thus saving the cost of special
housing. When water is softened at 210 degrees Fahrenheit
the reduction in hardness is greater in 10 minutes than it
is in five hours at 50 degrees Fahrenheit. Twenty-four
hour treatment at 50 degrees Fahrenheit does not bring down
as much scale forming matter as 10 minutes at 210 degrees
Fahrenheit. The particles formed at higher temperatures are
larger than those formed at low temperature. Measurements
by S. T. Powell, author of Boiler Feed-Water Purification,
show that the precipitated particles when precipitated
at 210 degrees Fahrenheit are 21 times as large

as those precipitated at 50 degrees Fahrenheit at the end
of a 10 minute reaction period. The velocity of falling
particles can be calculated from Stoke's formula:

$$V = \frac{2}{9} \quad \frac{D - d \; gr^2}{N}$$

V = Velocity of falling particles

D = Density of particles

d = Density of water

g = Acceleration due to gravity

r = Radius of particles

N = Coefficient of viscosity

This increased size of particles secured with the hot
process softener makes filtration more rapid and complete.

PROPOSAL NO. 3

The third proposal is the recommendation of the aban-
donment of the college wells as a source of water and the
purchase of the already partially softened water from the
city of Manhattan, passing this water through a zeolite
softener to still further reduce its hardness. This treated
city water has a total hardness of 125 parts per million
calculated as calcium carbonate. By means of a zeolite
softener this water can be easily reduced to zero degrees
hardness. Zeolite softeners have several advantages over

other methods of softening:

1. They are capable of giving practically complete removal of lime and magnesium salts.

2. They require less supervision than lime-soda ash softeners.

3. No chemicals are added to soften the water.

4. They may be placed on the main supply line and will cause only a slight loss of pressure.

5. No repumping of this softened water is required.

6. No appreciable amount of scale will deposit in the boilers.

7. The system will operate efficiently with fluctuating hardness of the untreated water by simply regulating the rate of flow.

Zeolite softeners cannot operate efficiently on turbid waters or on waters of a high degree of hardness. For this reason it would not be advisable to use a zeolite softener on college water as this would require a preliminary partial softening with lime, thus necessitating the installation of two softeners of different types. For such a small plant this would not be an economical plan.

With the present installation it is sometimes necessary to draw on the city water supply in order to supplement the supply from the college wells. This happens frequently during the hot and dry summer months. This gives of course,

a water fluctuating widely in hardness, a difficult one to
handle by any process. For such a water the zeolite
softener is most easily controlled but requires a softener
of large enough size to take care of the maximum hardness
found in the water at any time. This plan does not require
the attention of a chemist, as the analysis needed for its
control is very simple. The determination of total hard-
ness by the standard soap solution method is all that is
required. The results of this test, which requires but a
few minutes and no special skill or knowledge of the
chemistry involved, enables one to control the process by
simply adjusting the rate of flow of the water through the
softener. The test is made periodically on a sample of
water which has passed through the softener. If the water
is found to be insufficiently softened, the rate of flow is
decreased proportionately.

DISCUSSION OF LOSSES DUE TO SCALE

As previously stated, one of the losses incident to
using an improperly treated water for boiler feed purposes
is the loss of heat due to the insulating properties of the
scale caused by the use of this water. It is difficult to
estimate the insulating effect of scale of various thick-
nesses due to the difference in the character of the scale.

Several attempts have been made but the results are not all in agreement.

F. L. McCune, in a bulletin describing Magic Boiler Preservative, shows the following fuel losses with scale in boilers:

Thickness of scale in inches	Per cent loss of fuel
3/64	9.55
1/16	12.75
1/8	22.95
1/4	41.31

S. T. Powell believes that for a thickness up to one-eighth of an inch, the loss of heat may vary in individual cases from insignificant figures to 10 or 12 per cent. This loss increases considerably with the thickness of the scale but the mechanical structure of the scale is of as much importance as the thickness in producing loss. Another estimate of this loss is as follows: for a thickness of three-sixteenths of an inch, a loss of 20 to 30 per cent, for one-fourth inch a loss of 50 per cent and for a thickness of one-half inch a loss of 150 per cent.

The scale found in the tubes removed from the old boilers at the college before any attempt was made at treating the water was between one-half and three-fourths of an inch thick. It is impossible to state accurately

in figures the loss caused by a scale of this thickness but
it would not be less than 100 per cent. The fuel consumed
in the production of steam for the year 1920-21 cost
$49,103.22. Assuming a 150 per cent heat loss, $24,552.61
worth of fuel would have been wasted for this period.

The scale caused by using water treated by the method
of softening used at the present is between one-eight and
one-fourth inch thick. This would cause a heat loss of
about 25 per cent or a waste of $9,821.04 worth of fuel
each year.

The average thickness of scale given by the use of
water treated by the lime-soda ash method as suggested in
proposals no. 1 and no. 2 should not be over one thirty-
second to one-sixteenth inch. This would give a heat loss
of only 5 per cent costing $2,339.00 per year. The loss
of heat due to scale caused by the use of water treated by
a zeolite softener as in proposal no. 3 should be negli-
gible.

Another loss is that due to the necessity of removing
the scale from the boiler tubes. When properly treated
water is used very little scale is deposited.

A third loss comes from the necessity of having to
replace burned out tubes. The scale forming on the inside
of the tube acts as an insulation retarding the transmission

of the heat from the fuel box through it. This causes the
tubes to overheat and to burn out.

From August 1929 to April 1932, 180 boiler tubes have
been replaced in the Kansas State College power plant. The
cost of these tubes is about $8.00 and the cost of in-
stalling them about $3.00 each. During the same period,
there have been 58 shutdowns for the purpose of removing
scale. These shutdowns cost about $30.00 each. The adop-
tion of either plan no. 1 or no. 2 should reduce the shut-
downs necessary for removal of boiler scale by 50 to 75 per
cent. The use of plan no. 3 should reduce these shutdowns
to zero. Tube replacements due to burning out should be re-
duced in still larger proportions.

ECONOMIC TREATMENT OF PROPOSAL NO. 1

Analysis of raw water expressed in parts per million:

Total solids	576.25		
Ignition loss	58.40		
Sulphates	89.70		
Chlorides	18.76		
Alkalinity	205.6 (CO_3)	420.9 (HCO_3)	345 $CaCO_3$
Silica	22.40		
Iron and Aluminum	0.80		
Calcium	116.15		

| Magnesium | 25.00 |
| Carbon dioxide | 18.50 |

Theoretical combinations expressed in parts per million:

Magnesium carbonate	86.68
Calcium carbonate	240.13
Calcium sulphate	67.95
Sodium chloride	30.93
Iron and Aluminum	0.80
Silica	22.40

Total solids as determined from the theoretical combinations 510.63.

Total solids as determined by analysis minus ignition loss 518.85.

This close agreement tends to show the correctness of the analysis. Softening reagents required as calculated from the theoretical combinations per thousand gallons of water softened:

3.04 pounds lime (100% Ca (OH_2)) or 3.15 pounds (96.5% Ca (OH_2)).

.44 pounds of soda ash (100% Na_2CO_3) or .495 pounds (88.8% Na_2CO_3.

The cost of securing water by proposal no. 1 consists of the cost of pumping, which is the same as at present, plus the cost of softening, which is the same as at present except for the cost of an additional softening pit.

Cost of securing water by proposal No. 1

	Costs per year for present process	Costs per year for Proposal No. 1	Savings per year by use of Proposal No. 1
Cost of pumping	$610.28	$610.28	
Cost of lime	287.43	287.43	
Cost of soda ash	129.88	129.88	
Labor for softening	356.00	365.00	
Interest at 6% on cost of additional softening pit ($1,441.00).		86.48	
Total cost	1,383.59	1,470.07	
Saving in fuel			$7,482.70
Saving in removing scale and replacing tubes			1,076.24
Total saving			8,558.94
Net saving			8,472.46

ECONOMIC TREATMENT OF PROPOSAL NO. 2

	Costs per year by present process	Costs per year for Proposal No. 2	Savings per year by use of Proposal No. 2
Cost of pumping		$610.28	
Cost of lime		287.43	
Cost of soda ash		129.88	
Labor for softening		182.50	
Interest at 6% on cost of continuous softener ($3200.00)		192.00	
Total cost	$1,383.59	1,402.09	
Saving in fuel			$7,482.70
Saving in removing scale and replacing tubes			1,076.24
Total saving			8,558.94
Additional cost			18.59
Net saving			8,540.35

ECONOMIC TREATMENT OF PROPOSAL NO. 3

	Costs per year by present process	Costs per year for Proposal No. 3	Savings per year by use of Proposal No. 3
Cost of purchasing water		$1,366.12	
Interest at 6% on cost of zeolite softener($1089.00)		65.34	
Labor		182.50	
Wash water		54.60	
Maintenance		40.88	
Total Cost	$1,383.59	1,709.44	
Saving in fuel			$9,821.04
Saving in removing scale and replacing tubes			1,240.24
Total saving			11,061.28
Additional cost			325.85
Net saving			10,735.43

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