NOTES ON SOME MODERN TENDENCIES IN BOILER CONTROL WORK.

By

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Introduction.

The subject can be broadly classified under two headings: Water Treatment and Combustion. It is not the object of this paper to elaborate the methods of running efficiency tests and their attendant calculations, but rather to discuss the laboratory and factory work of the chemist in this more or less engineering subject. I think we can safely say that the day is past when accidents and expensive replacements to boiler plant are to be regarded as an act of God. Modern steam generating equipment is so costly and highly developed, that it becomes almost criminal to overlook the instruments and methods of control, which have been devised for its safeguarding and improved efficiency. Many power plants overseas maintain far more fully equipped and better staffed laboratories for the sole purpose of this control work, than our sugar industry possesses for the supervision of a complete factory.

It must not for a moment be thought that there is any intention or possibility of interference with the work of the engineer; but feed-water problems are almost entirely chemical, and combustion difficulties must be met with a full knowledge of the composition and requirements of the fuel employed. So that it is only by the closest dovetailing of the efforts of the engineer and chemist that the best results can be obtained from the mechanical equipment of the boiler, in its dealings with the chemical variations and vagaries of its fuel and water. The sugar industry has made costly mistakes in the past through the failure to recognise these principles, but I am sure the time has now come when we no longer have to make out a case for control, but rather have to give a fuller explanation of the methods of control necessary and available.

There is one point that I shall mention now, on which I shall probably strike some argument and differences of opinion. The analyses of water, steam, and flue gases must necessarily be the work of the laboratory. Any instruments used, whether of an indicating or a recording type, require standardizing and checking by means of laboratory analysis. It is logical to assume, therefore, that the laboratory should also be responsible for the care and maintenance of these same instruments. The possibilities and value of instrument control in any factory need not be enlarged upon, but it has been my experience that it is essential to have one person, or department, in charge of the running of such apparatus. If records and control work are valuable, then surely the instruments that give the results are themselves worthy of the small amount of regular checking and attention which is necessary to keep them functioning correctly.

Treatment of Raw Water.

It is not possible in a paper of this nature to make definite recommendations regarding the treatment of different water supplies at the factories. These will naturally vary considerably and must be the subject of an individual examination before deciding on any method of treatment. If the main supply is from a river it will be found that the Natal coast streams do not differ greatly in composition, subject, of course, to freedom from pollution, and some of the experience gained in dealing with the Umhlatuzana River water may be possible of application elsewhere. One of the first requirements is ample settling capacity, particularly when dealing with the river in spate.

Alum.—This is probably the oldest coagulent known in water treatment, and as "filter alum," or commercial aluminium sulphate, it is easily obtainable and is comparatively cheap. When sold as "alumina ferric" it does not indicate that the substance is an actual iron salt, as many believe, but simply that the particular source from which it was obtained, the bauxite, probably contained some iron as impurity. Its action with the natural alkalinity of the water, usually present as calcium or magnesium bicarbonate, is to form a flocculent precipitate of aluminium hydroxide, thus:

\[
\text{Al}_2(\text{SO}_4)_3 + 3\text{Ca} (\text{HCO}_3)_2 \\
\rightarrow \text{Al}_2(\text{OH})_6 + 3\text{CaSO}_4 + 6\text{CO}_2.
\]

The important part of this reaction is that it proceeds most rapidly to completion at a definite, optimum pH, which will vary with the particular type and composition of the water. The river water is usually of approximately 7.3 to 7.4 pH, and the point at which the best and quickest settling will be obtained is easily ascertained by a simple laboratory settling test. In normal working this lies around 6.6 pH, but this will probably vary in times of drought or flood. In rainy weather the amount...
of silt, and colloidal and clay-like material in the water, increases considerably, and the heavier flocculation of the aluminium hydroxide is required to envelop and carry down these impurities. The optimum pH at such times may fall to as low as 5.8. The disadvantage in the use of alum is that it is an acid salt, and excessive quantities, if unneutralized and passed on to the boilers, would cause serious corrosion. On examining the equation given above, it will also be noted that considerable carbon dioxide is formed, and thus it becomes necessary to use lime both for the neutralizing of any excess alum and the removal of CO₂. The water is usually saturated with the gas at the particular temperature, and vigorous agitation, or some simple degassing device, will be found to greatly reduce the lime requirement. The gas in solution will cause a low pH to be shown in the treated water, and this may give rise to an apparent anomaly when make-up is later mixed with hot condensate. Warning must be given against the mistake of adding alum and lime at the same point. This will greatly decrease the efficiency of flocculation and increase the amount of chemicals required, as already pointed out by Bond. Sufficient time should be allowed for the alum precipitate to settle; then the lime should be added and the water passed on to the sand filters, if this equipment is available. Control of a plant such as this is comparatively simple. Tests for pH of the water should be done—just after the addition of alum, at the point of complete settling, and after the completion of the lime neutralization—at intervals of from one to two hours. The ideal is to have a pH recorder on the alum-treated water. Naturally, densities of alum and milk of lime will be controlled by laboratory checks.

This treatment of the water must not be confused with softening processes. The permanent hardness will probably be added to, as calcium sulphate is formed in the reaction, and the water will be saturated with this salt at the particular temperature.

Softening.

Again depending on local conditions, a softening plant may be used either with or without previous flocculation and settling. With much suspended matter in the water it is not an economical proposition to throw the full burden of clarification upon a softening plant. Rather is it preferable to clarify all the water required for the factory, and soften that portion in which hardness will be detrimental.

The lime-soda process of water softening is too well known to require a full description here, and its control is mainly carried out by titrations giving carbonate and caustic soda alkalinitities, and the temporary and permanent hardness due to lime and magnesia.

The reactions of lime and soda ash with calcium and magnesium salts will be known by all, and the calculation of the chemicals required is easy if it is remembered that magnesium differs from calcium in that its carbonate is more soluble than its hydroxide; and magnesium permanent hardness, plus lime, forms calcium sulphate. Therefore we require to add the temporary hardness to the total magnesium hardness in the calculation.

With results in parts per 100,000—

1 part CaCO₃ requires 0.74 parts Ca(OH)₂ for total temporary and Mg. permanent hardness.
1 part CaCO₃ requires 1.06 parts Na₂CO₃ for permanent calcium hardness.

1 part per 100,000

\[ \frac{0.7}{437.5} \times 1,000 \text{ ozs. per 1,000 gals.} \]

\[ = 1.6 \text{ ozs. per 1,000 gals.} \]

Therefore the lime hydrate required

= Temporary hardness + total Mg. hardness × 1.184 ozs. per 1,000 gals.,
and soda ash required

= Permanent hardness × 1.696 ozs. per 1,000 gals.

Another method for computing the lime and soda requirements is the formula due to Dr. Hale:

\[ \text{(Alkalinity} \times 0.44 + \text{free} \text{CO}_2) \times 0.0106 \]

= lbs. CaO per 1,000 gals. feed.

Also—

\[ \text{(Total hardness} - \text{total lime or total magnesia as CaCO}_3) \times 0.0047 \]

= lbs. CaO per 1,000 gals. feed.

\[ \text{(Total hardness} - \text{alkalinity expressed as CaCO}_3) \times 0.009 \]

= lbs. Na₂CO₃ per 1,000 gals. feed.

Of recent years the use of sodium aluminate has come into prominence for water softening, either by itself, or in conjunction with a lime-soda plant. It is said to aid the settling of calcium carbonate, and with magnesium salts forms a flocculent precipitate of good coagulating power. Where organic matter is present in the water, aluminate is stated to succeed when lime and soda fail, as the coagulent minimises the colloidal interference of organic matter and double magnesium salts.

Matthews puts forward many advantages for sodium aluminate, chief of these being the removal of silica, and stresses the fact that, being an alkaline
Salt, danger of corrosion is eliminated. Its value in the prevention of silica scale lies mainly in the formation of a complex magnesium alumino-silicate, a flocculent precipitate. The removal of silica with high calcium and low magnesium waters is not so definite; and possibly herein lies one of the reasons for its lack of positive results in this country. Bond mentions this point; and most Natal coast streams are not particularly high in magnesium salts.

Sodium aluminate is costly in this country, and it must be borne in mind that any benefits attending its use will be lost, if it is added in a plant together with the aluminium sulphate and lime. The soda aluminate and alum react to give aluminium hydroxide, which can be obtained far more cheaply. Matthews also stresses the use of an excess of aluminate, leaving soluble alumina in the water, but U. R. Evans states that “the fact should be borne in mind that aluminium salts tend to become acid by hydrolysis when heated, and “Excessive amounts of aluminium compounds should be avoided, to avoid risk of forming hard sodium aluminium silicate scale in the boiler.”

In practice it will be found that with settling tests and careful pH control, there will be little difficulty with excess aluminium, in using the aluminium sulphate—natural alkalinity floc. for clarification; and the subsequent liming will be mainly for the purpose of removing CO$_2$ and bringing the pH back to 7.0.

A useful test for small quantities of aluminium is the analysis described in Scott using Alizarin S. as indicator.

**Conditioning and the Requirements of Feed.**

Whatever the method of softening or clarification adopted, it will not be possible to remove the final traces of dissolved salts from a water. There will usually be a residual hardness of from 3 to 5 degrees, some sulphate, carbonate, hydroxide, and possibly chloride and silica. Thus it becomes necessary to take some additional steps in the treatment of a water, before it is suitable for use in a modern steam plant employing fairly high pressures, and of a high evaporative capacity. It must be remembered that types and amounts of scale, which were quite harmless at the gentle rates of steaming of a few years back, are now dangerous even in thin layers when boilers are being driven hard. Under these high load conditions the layer of scale next to the metal is dried out, forming such an efficient heat insulator that the metal is exposed to overheating and burning.

For many years “boiler compounds” enjoyed a great popularity, and were regarded as the panacea of all boiler ills, to such an extent that many waters were trustingly fed to boilers, even though they contained enormous quantities of dissolved solids of an undesirable type, in the blind belief that the magical compound, plus an odd spot of blowing down, would fix things up beautifully. May I even have the temerity to suggest that such a position exists in the boiler plants of a few of our mills to the present day?

Shortly after this enthusiasm for internal treatment, we find the pendulum swinging to the opposite side of the scale, and engineers refusing to add anything in the form of a conditioner to the feed tank, expressing the opinion that “we must not turn the boiler into a chemical factory. The place for treatment of water is prior to its entering the feed line, and only a pure water should reach the boiler itself.” In this last sentence lies the crux of the whole position—“a pure water.” Whether we like it or not, the interior of the boiler is, and probably always will be, worthy of the name of “chemical factory.” No matter how careful the treatment, small quantities of dissolved substances are bound to reach the boiler drum, and as efficiencies improve, evaporative rates increase, and pressures rise, so does the concentration of these traces of substances take place and become more important.

Even the use of large proportions, or as much as 100 per cent., of condensate does not alter this position, whilst there are such things as carry-over, condenser leakage, calandria, coil and other heating apparatus failure, to worry us. Other dangers are incurred by the presence of dissolved gases, and even the slightest trace of oil.

Returning to the question of scale-forming material; recognising the impracticability of removing all dissolved substances from a water, the problem is to change them to such a form that they will not deposit as a heat-insulating layer on the metal; or to add substances which, by the influence of their presence in solution, will inhibit this form of deposit.

**Hot-process Phosphate Softening.**

It is possible to reduce greatly the amount of conditioning necessary with a water, by the use of an “after softener” of this type. Where lime-soda or alum treatment is used on the main water supply, reducing a variable hardness to roughly 2 to 5 parts per 100,000, that quantity to be used for feed make-up may with advantage be treated with di-sodium phosphate in a hot-process softener, equipped with proportioning devices. Calcium phosphate and magnesium hydroxide are precipitated at 225°F. and the settled water may then be passed through pressure filters, preferably filled with magnetite or anthracite coal to eliminate silica. It is advisable to run a plant of this sort so that a
slight excess of phosphate radical is left in the water, to act as a conditioner. A hardness figure as low as 0.5 part per 100,000 should be attained with such a softener.

Salts which form a troublesome scale are mainly those with an inverted solubility curve, such as calcium sulphate. To prevent their deposit it is necessary to have in solution also, acidic radicals, whose preponderance will throw out of solution salts with a positive temperature coefficient, these forming a soft sludge, as opposed to a hard scale. According to the ionic theory, in a saturated solution, the product of the molar concentrations of the ions is a constant. So that if, to a saturated solution of one of the less soluble salts, a concentrated solution of a very soluble salt having one ion in common with the first salt is added, partial precipitation of the first salt will take place. Therefore, in a solution saturated with both calcium sulphate and calcium carbonate, the addition of sodium carbonate will precipitate sludge-forming calcium carbonate, because by the addition of the excess carbonate ions the solubility product of the calcium carbonate is exceeded, and to re-establish equilibrium some of the calcium carbonate is thrown out of solution.

The above briefly explains the principles upon which the condition of feed water is based. However, sodium carbonate is not a suitable substance to use, as at boiler temperature and pressure it is largely hydrolysed, forming sodium hydroxide and giving off CO₂. This leads to excessive caustic alkalinity of the boiler water, which may give rise to embrittlement.

**Caustic Embrittlement.**

A slightly alkaline water may well be regarded as non-corrosive, but where high proportions of carbonate exist, this is broken up and the hydroxide is formed under high-pressure conditions. The hydroxide will gradually become concentrated, especially in crevices, at seams, rivet-crannies, or any fissures or hair-lines, until finally such a concentration of alkali is reached that corrosion can take place.

This hydrogen-evolution type of corrosion occurs in the hot, dilute alkali, and is due to the solution of iron as sodium ferroate (Na₃FeO₄).⁹

The different theories that have been put forward on the subject of embrittlement, and the arguments thereon, are legion; but the practical proof of results has shown that where certain specified water conditions have been maintained, embrittlement has never been found.

These conditions were originally laid down by Parr and Straub¹⁰ and specify the provision of a definite excess of sodium sulphate in the feed water. If the concentration of (SO₄)²⁻ ions is great enough, then the solubility product of sodium sulphate will be exceeded before that of the hydroxide, with the result that the former salt will be deposited in any crevices.

It must be recognised that embrittlement is a form of corrosion attack, and where the metal is under any stress the action becomes intergranular, giving rise to cracks. It seems to be fairly well established that where high stresses exist, either through excessive riveting pressure or other cause, embrittlement will take place if the ratio of hydroxide to sulphate is sufficiently high in the boiler water; but where high caustic concentration is absent, embrittlement will not take place even in the presence of stresses and strains. Embrittlement must not be confused with typical "fatigue" cracks. For a more detailed discussion of the subject see Evans¹¹ and Parr.¹²

The standards laid down by the American Society of Mechanical Engineers are as under:

<table>
<thead>
<tr>
<th>Operating pressure (lbs. sq. in.)</th>
<th>SO₄ parts per 100,000</th>
<th>PO₄ parts per 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0.31</td>
</tr>
<tr>
<td>150</td>
<td>100</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>1.13</td>
</tr>
<tr>
<td>210</td>
<td>100</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>3.45</td>
</tr>
</tbody>
</table>

The addition of sodium phosphate to the feedwater, so as to maintain a sufficiently high PO₄ concentration to always exceed the solubility product of calcium phosphate, before that of calcium sulphate, will ensure the calcium precipitation as the former salt. This tri-calcium phosphate, Ca₃(PO₄)₂, forms a soft, non-adherent sludge instead of scale. The following table, from R. E. Hall, shows the concentrations necessary.
There is some difference of opinion amongst authorities as to what is the best form of sodium phosphate to use. Four salts are available.

1. Primary sodium orthophosphate, $\text{NaH}_2\text{PO}_4$.
2. Secondary sodium orthophosphate, $\text{Na}_2\text{HPO}_4$.
3. Tertiary sodium orthophosphate, $\text{Na}_3\text{PO}_4$.
4. Sodium metaphosphate, $\text{NaPO}_3$, available commercially in the form of "Calgon" (E. R. Hall), which is actually the hexametaphosphate ($\text{NaPO}_3\text{O}_6$), plus a small proportion of tetrasodium pyrophosphate $\text{Na}_4\text{P}_2\text{O}_7$.

Glinn favours the use of (3); Powell prefers (1); Powell, McChesney and Henry specify (2); and Matthews advises (4). The latter author gives a good discussion of the action of the phosphates, and stresses that a hydroxyl concentration of caustic alkalinity of at least 10 parts per 100,000 should be provided; as otherwise, instead of the desirable tri-calcium phosphate, both di-calcium phosphate and mono-calcium phosphate will be produced. However, this alkalinity is usually easily attained in the boiler. But with (1), (2) and (3) there is always the danger of deposit or scale in the feed lines and economizer, and direct injection of the phosphate to the boiler (preferably distributed through a T-piece at the rear of the steam drum) is advisable. Bond rather discounts the possibility of feed line deposit.

Number (4), Calgon, on the other hand, possesses the unique property of holding up calcium salts in solution until, on reaching the boiler, the high temperatures and the presence of hydroxide bring about decomposition and the formation of salts (1) and (3).

Of the four salts, the first is definitely acid, the second and the third are alkaline, and the fourth is approximately neutral in dilute solutions. Therefore, from what has been said in the preceding paragraph, both (1) and (4) will tend to neutralize any excess caustic present in the boiler, and consequently it will be realised that more alkali will be required when the metaphosphate is used in place of the secondary or tertiary orthophosphates.

Actually, grave misstatements are often made regarding the chemistry of the phosphate reactions. The tertiary salt is stable only in the solid form, and is prepared as follows:

$$\text{Na}_3\text{HPO}_4 + \text{NaOH} \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O}.$$

In solution this action is reversible.

Similarly,

$$\text{NaH}_2\text{PO}_4 \rightleftharpoons \text{NaPO}_3 + \text{H}_2\text{O}.$$

At high temperatures of solution, and at the correct pH, however,

$$\text{NaPO}_3 + 2\text{NaOH} \rightarrow \text{Na}_3\text{PO}_4 + \text{H}_2\text{O}.$$  

The actual interaction of phosphate with the calcium hardness, again presuming a sufficiently high pH, may be simply stated,

$$3\text{CaSO}_4 + 2\text{Na}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + 3\text{Na}_2\text{SO}_4.$$  

Phosphate conditioning has been very successful in a number of high-pressure plants, where high load conditions and long steaming hours necessitated scale-free boilers. Under most conditions, if no facilities exist for direct injection of chemical, the metaphosphate offers the most satisfactory form for addition to the feed. A sufficient alkalinity of the feed must be maintained, but with waters containing calcium sulphate, owing to the conversion to sodium sulphate by the phosphate, the sulphate-alkalinity ratio to prevent caustic embrittlement will be more easily established. At this point it might be mentioned that the argument still waxes strongly regarding the merit of the excess PO₄ radical in preventing embrittlement. Extraordinary claims have been advanced in its favour, which would be indeed highly convenient if correct, but no definite proof has yet been produced either way. Be that as it may, phosphate is effective for scale prevention, and though it is doubtful if any genuine cases of embrittlement have been known in the presence of a maintained excess of PO₄, the bulk of evidence is in favour of a high sulphate-alkalinity ratio for preventing this latter type of failure.

Dissolved Oxygen.

Here we come to one of the most essential items in boiler control work. It has long been known that the presence of excessive quantities of free oxygen in the feed gave rise to corrosion. But it was not until the electrochemical nature of corrosion, as opposed to straight oxidation, was accepted, and the pioneer work of U. R. Evans on the theory of differential aeration was fully understood, that its real significance was appreciated. Differential aeration has been discussed already in papers given locally by Dr. Hedley, and will not be enlarged upon here. Matthews and Lewis and Irving tend to the opinion that most boiler corrosion is due to this form of attack, but it is always difficult to judge the nature of actions taking place at high temperature and pressure, by the results when examined in the cold under atmospheric conditions. Be that as it may, dissolved oxygen is highly dangerous, as we know to our cost locally from the results of pitting and corrosion, and it must be reduced to an absolute minimum in the feed.

Methods of removal.—One method is to pass the water over large quantities of perforated metal, but
an installation of this sort must be rather large, and carefully arranged, so that rust does not obstruct the flow. The iron used should be of a type that rusts readily, such as an impure manganese steel, and should present a large surface. In many cases turnings, or fine iron wool, are employed. The Kestner plant regenerates half the material used daily, by passing de-gassed water in a reverse flow through the steel wool, thus reducing the rust once more to the easily oxidized ferrous hydrate. Where iron is used in this manner the waste material is simply being substituted for the metal of the boiler, which would otherwise be attacked.

Other chemical methods of de-aeration employ substances such as sodium sulphite, ferrous sulphate, and the alkaline tannates.

The modern tendency is to employ physical methods as far as possible, which will generally reduce the dissolved oxygen to 0.1 c.c. per litre or less; and in high pressure plants, where the utmost in de-aeration is necessary, to use a subsequent chemical treatment, usually with sodium sulphite.

Physical de-aerators use fine division of the water into droplets, steam, partly evacuated chambers, and sudden temperature drops as their means of de-gassing. In plants such as the ‘Weir’ the operation is done in two stages. The water is passed as a spray into a partially evacuated chamber, where it meets, and cools, the vapour from the second stage, in which the water is boiled violently by exhaust steam entering through a perforated distribution plate.

Whatever the plant employed it will require, and is worth, regular checking and maintenance; and care must be taken to see that no contamination takes place after the water leaves the de-aerator, through leaky pump glands or the addition of oxygen-containing condensate.

**Condition of Boiler Waters.**

A great deal of the discussion on the actual internal conditions of the boiler has already been given under the headings of Softening, Feed Water Treatment, and Conditioning. To recapitulate, if we see that the feed-water has a minimum of dissolved oxygen, a minimum of total solids, a definite caustic alkalinity giving a pH round about 8.0, sufficient free PO₄ to prevent sulphate scale formation, and no oil, all that remains to be done is to keep a careful check on the concentration of solids in the boiler, preventing an undue rise by blowing down, and to see that the sulphate-carbonate ratio does not drop to the point where caustic embrittlement may occur.

Of course, the solids concentration must be kept down to prevent foaming or priming, and the degree of concentration which is possible without ill results will vary with different plants. This is best determined by an examination of the steam itself, as will be described later. Whilst on the subject of priming, I might say that any one who wishes to spend a quiet evening acquiring a beautiful head-ache, has only to delve, and not very deeply, into the voluminous literature on the problem. I shall not attempt to give references; they would occupy a paper of their own. The facts are that we have a multitude of theories, into which none of the experimental work seems to fit; and a significant point is that most papers on priming or foaming have, as their concluding heading, not “Conclusions” but “Speculations.” A boiler, even a small experimental boiler, is a nasty, unscientific piece of apparatus with which to conduct investigations.

In practice, a point of solids concentration will be found, above which trouble will almost invariably be experienced. Keep below this point.

I have now very briefly described most of the principles governing feed and boiler water control, and shall go on to discuss some interesting aspects of sampling and analysis of these waters. I do not intend to run through a full scheme of analyses, as this has already been done in our report from the Chemical Control Committee; but instead will touch on optional methods, and errors in analysis, types of instruments used, and aids to representative sampling.

**Hydrogen Ion Concentration.**

Methods of pH determination are either colourimetric or electrometric. Till recently the former were used almost exclusively for all control work. But it is now recognised that colourimetric methods are subject to many errors due to substances interfering with the colour change. In unbuffered solutions especially, such as fairly pure condensate, results may be misleading unless the pH of the solution being tested, and the indicator, are approximately the same. Methods using iso-hydric indicators are not altogether convenient for routine work.

Electrometric methods have now been developed which give exceedingly accurate results and are easy to use. Several outfits are on the market which use a glass electrode, in conjunction with an ordinary potentiometer circuit and a valve amplifier. These give the most accurate results, particularly on unbuffered solutions, up to a pH of 9.0. Above this point cations such as sodium and lithium interfere, penetrate the glass, and cause a low e.m.f. But these errors are reproducible, and so it is possible to apply correction factors; and with high pH, say over 11.0 in a boiler water, it is advisable to calibrate.
the instrument with a buffer of approximately the same pH and cation concentration as the solution to be tested.

Industrial type instruments are now available, using a glass electrode in a flow-through cell, and a self-balancing, recording or indicating potentiometer. These are useful at the water treatment plant, especially where alum is used; with a phosphate softener; in the feed water; and, if suitable apparatus for continuous samples is installed, on the boiler water itself. Under some conditions, and particularly with high alkalinities, an antimony electrode may be more suitable for recording and controlling instruments than the glass. A Kent "Multelec" instrument, using an antimony electrode, has been in use for two and a half years at the Refinery on lightly buffered liquors at a high temperature, and has proved eminently satisfactory. This instrument is run directly from the mains, employing battery current only for the actual galvanometer circuit, this current being automatically standardized once an hour, by a most ingenious device, against a standard cadmium cell. The machine can also be used as an automatic controller. Other outfits on the market are the Cameron, the Coleman, and the Beckman, all using glass electrodes; all are available as indicators and recorders; and they are of American manufacture.

Some people are still inclined to doubt the reliability of pH control apparatus, so it may be of interest to describe briefly here the installation in use at the Rochester Gas and Electric Corporation power plant, which is equipped with 12 boilers of 60,000 lbs./hr., each boiler at 220 lbs./sq. in., and 3 boilers of 250,000 lbs./hr., each boiler at 710 lbs./sq. in. The effluent from the phosphate softener has a pH of 10.1, and at first some difficulty was experienced with deposits in feed lines. The solubility product of calcium phosphate is quite low at the temperature of their feed, and precipitation is governed not only by ion concentration and temperature, but is favoured by high pH. So sulphuric acid was added to the feed to reduce the pH to 8.8. This acid addition is done automatically by an antimony electrode pH controller working in conjunction with a Bailey flow controller. The trusting of the addition of this strong acid to an automatic controller has not only shown itself justified, but a correct sulphate ratio has been maintained, the total solids entering boilers and the amount of blow-down required were reduced, and scale formation and the slightest trace of corrosion were entirely absent even after runs of 100 days continuous steaming. It might be mentioned that for a long time the high-pressure section of this plant was using about 95 per cent. make-up!

So pH recorders and controllers are certainly worth while. If only one recorder can be installed as a start, the feed line will probably be the most valuable place in which to work it. But a laboratory glass electrode equipment should be owned by all mills as a reference standard.

**Electrical Conductivity.**

For many years conductivity measurements have been used in the detection and estimation of condenser leakage, and, to a slightly less extent, for the approximate estimation of total dissolved solids in a water, such as boiler water.

In principle, briefly, the conductivity of a solution is a function of all the ions present (as distinguished from hydrogen ion concentration), and when the total number of ions increases, the conductivity increases, and vice versa. Also, having determined the conductivity of a solution of certain electrolytes at two different concentrations, the concentration of any solution of these same electrolytes between the two previously determined points may be computed from its conductivity.

Specific resistance is defined as the resistance of a unit cube of a conductor of a given material, and is expressed as ohms per centimeter cube. The reciprocal of this resistance is the specific conductivity.

So, having determined by analysis the total solids and conductivity of a water of given composition at a sufficient number of different concentrations, the solids may afterwards be determined with fair accuracy, in the same type of water, by conductivity measurements alone. This is extremely useful in the estimation of solids in boiler waters for blow-down control, as the relative composition of the water at any one factory will not alter greatly from day to day. Tests of this nature should be done once or twice per eight-hour shift on each boiler.

A useful instrument for work of this sort is the "Dionic" tester, consisting of an ordinary "megger," a conductivity cell and meter. The cell consists of an outer sleeve electrode surrounding an accurately bored and calibrated glass tube, in which the inner electrode is free to slide, thus giving the compensation for temperature. In the laboratory, for finer measurements, an A.C. bridge is usually employed, using a reed hummer giving a supply of approximately 1,000 cycles per second. A range switch is also necessary to give variable resistances from 1 to 10,000 ohms, or from 1 to 0.0001 mhos. A telephone is used with the bridge. Visual units are now available, doing away with the telephone, and showing directly the out of balance with a galvanometer. For the recording of conductivity two cells are usually used. These are wired to opposite arms of the bridge, one containing, or having passed through it, the solution under test, and the other containing...
The four arms are composed of small platinum wire spirals, heated by battery current regulated by resistance R. Two opposite spirals, R1 and R4, form one cell, and R2 and R3 the other. The cells are connected to a self-balancing potentiometer circuit and a recorder. If hydrogen gas is passed through both cells containing the heated spirals, the bridge remains balanced. In practice a small portion of the water is bled off the supply under test, and hydrogen is bubbled through it. This 'scrubs out' the air, or mixture of nitrogen and oxygen, which passes up past the one pair of heated spirals R1, R4. Then, the thermal conductivity of the gas mixture differing from the pure hydrogen round R2, R3, less heat will be drawn from the spirals. The temperature will rise, the resistance will alter, and the bridge will be thrown out of balance. This is corrected, and the amount of correction is shown on the suitably calibrated chart of the recorder.

Perley describes a method of electrometric titration with the Winkler method, which does away with the errors attendant upon the nature of the starch indicator and the temperature influence. The description which he gives regarding sampling methods for dissolved oxygen determination is so concise and well put that I take the liberty of quoting it here in full.

"Sampling.—All oxygen must be removed from the sampling system before sampling is begun. When the water is at elevated temperatures and pressures, it is necessary to avoid flashing of the sample. The flow to the sampling bottles should be controlled by adjusting a valve on the discharge side of an adequate cooling coil. The temperature of the water at the sampling time should be slightly below that of the room temperature. The temperature of the sample bottle should not be allowed to decrease 1° C. between the time of sampling and the time of analysis. Hence, the temperature at the sampling point preferably should not exceed 30° C. (86° F.).

Three samples are collected in series in sampling bottles equipped with rubber stoppers and with inlet and outlet tubes. The sampling bottles should be slightly oversize and should have narrow mouths designed to accommodate ground-glass stoppers. The end of the glass stoppers should be ground to a semi-conical shape to prevent trapping of air bubbles when replacing stoppers. No trace of a gas bubble can be tolerated in the top of the sampling bottles. Two 250 ml. samples and one 500 ml. sample should be taken.

The water sample should enter one of the 250 ml. bottles through a tube extending to the bottom. The sample overflows through an outlet tube at the
top into the 500 ml. bottle intake tube. This overflows into the second 250 ml. bottle. McLean sampling tubes may be used in place of the bottles. Glass-to-glass butt connections should be provided for all connections. Rubber tubing is used merely to hold the connections in place. At least seven times the total volume of the three sampling bottles should be withdrawn before the sampling is stopped."

Sampling of Boiler Waters.

At the 1938 Conference I drew attention to the utter futility of basing control work on haphazard samples drawn from the gauge glass cock, without cooling, into an open container. This view then raised some argument, so I shall enlarge on the matter here. Present in the water are usually suspended particles of substances with normal, and others with inverted, solubility curves. If cooled down without any filtration therefore, the latter class of salt, like calcium sulphate, will go into solution, while the former may be even increased by further precipitation. Then, too, evaporation and concentration of solids is rapid, extremely variable, and incapable of correction by factors. The absorption of CO₂ is considerable, and the nett result may well be that on analysis we find a value for hydroxide-carbonate ratio which may be the very reverse to the true figure as existing in the boiler! Hence, it is necessary, not only to cool the sample to atmospheric temperature before drawing off, but to filter it as well as possible at boiler temperature and pressure. For further support of this argument see Partridge and Schroeder, Elms and Beneker and Johnston.

The sampling arrangement which we now use at the Refinery is shown in Fig. 2. below, which is self-explanatory. The sample should be drawn off into glass bottles fitted with overflow tubes, as for the dissolved oxygen sample.

Check on Priming, and Control of Steam Purity and Purification Equipment.

Electrometric methods come to our rescue here, and enable a very close watch indeed to be kept on the quality of the steam. As pressures rise, so boiler drums become relatively smaller, and with the modern type of water tube boiler, steaming above-rated capacity, there is the ever-present danger of carry-over. Apart from possible deposits and corrosion of turbine blades, as well as all the well-known troubles, it must be remembered that moisture carried over with steam is only inert matter, and represents just that much loss in power production. Hence the desire for the installation, and control, of the most efficient steam washer that can be devised.

Steam leaving the boiler may be bled off through a small line, passed through an efficient condenser similar to that described under "Sampling," and the condensate either collected in closed bottles of Pyrex glass, or else passed through the cell of a conductivity recorder such as the Kent "Multelec." Owing to the nature and purity of this condensate, it is essential that there should be no metallic contamination during the condensation and cooling. The sampling line should preferably be of stainless steel tubing, and the condenser coil should be made of block tin. With a continuous recording apparatus,

Richard Ulmer described an electrometric method for the measurement of contamination, which should have several applications. Two cells containing
identical electrodes are used. These are both wired to a voltmeter using the ordinary 220-volt a.c. current. In one cell a sample of pure condensed steam (distilled water) is placed, and in the other a sample of the condensed contaminated steam under test. The test sample is then added from a burette to the cell containing the distilled water, until the electrical conductance is shown to be the same as that in the cell which contains the contaminated sample. Thus a direct method for the measurement of the volume of contaminating liquid is available.

**Determination of Hydroxide and Carbonate in Boiler Waters.**

The methods already described in the Chemical Control Committee report may with advantage be used as a start in the determination of these two items. But mention must be made here of the work of Partridge and Schroeder and Collins and Schroeder who have shown errors which can arise in the ordinary phenolphthalein-methyl orange titration. Figures for hydroxide are not so much affected, but the carbonate as usually determined is probably reported rather higher than the true figure existing in the boiler. Rapid absorption of the carbon dioxide by samples on even brief exposure to the air contributes largely to this effect. The authors recommend the determination of carbonate by an evolution method, in which the carbon dioxide is liberated by an excess of acid and heating, and is then carried by an air stream into an excess of standard barium hydroxide, precipitating barium carbonate. The residual barium hydroxide is then titrated with standard acid. Details of the apparatus and manipulation will not be entered into here.

However, the knowledge of the existence of these errors should lead us to use more extensively the electrometric methods available, and greater reliance should be placed on results shown from the potentiometric determination of pH in boiler concentrates.

**Sulphate Determination.**

The gravimetric precipitation with barium chloride still remains more or less the standard, but this is time-consuming, and where a number of determinations are to be made the recently developed volumetric methods should certainly be investigated. The method due to Schroeder using tetrahydroxyquinone as an internal indicator, has been found quite satisfactory by the writer for the determination of small concentrations of sulphate; provided the silicate, magnesium, and carbonate ions are not present in too high a concentration. As a matter of interest to chemists, the method is set out here-under.

**Reagents needed.—**(1) A 0.025 N barium chloride solution, standardized gravimetrically. (2) A mixture of potassium chloride and tetrahydroxyquinone, prepared by grinding the disodium salt of tetrahydroxyquinone with dried potassium chloride in a 1 to 400 ratio.

**Procedure.**—A 25 c.c. sample, containing between 2 and 20 mg. of sulphate, in a 150 c.c. Erlenmeyer flask, is carefully neutralized until it is just acid to phenolphthalein. The hydrochloric acid used to acidify the sample should not be stronger than 0.030 N and must be added carefully from a burette. The sample should be below 30°C.

Add 25 c.c. of ethyl alcohol or 25 c.c. of alcohol denatured by formula 30.

Add 0.20 to 0.22 gram of the tetrahydroxyquinone-potassium chloride mixture. It is best to use a small cup to measure out the mixture. Swirl the flask until this is dissolved. This will give the solution a fairly deep yellow colour.

Run in the 0.025N barium chloride at a steady dropping rate, with constant swirling of the flask, until a brown colour begins to form. This is not the end point but indicates its approach. Add the barium chloride from here on, two or three drops at a time, with steady swirling until a red colour appears; this is the end point. The red colour appears throughout the body of the solution and not as spots of colour. If the sample contains between 2 and 20 mg. of sulphate this titration will require less than 17 c.c. of the barium chloride solution.

After deducting the 0.1 c.c. blank, each cubic centimetre of the 0.025 N barium chloride solution is equivalent to 1.2 mg. of sulphate.

If more than 0.6 mg. of phosphate is present, the blank should be increased. For concentrations from 0.6 to 1.2 mg. of phosphate the blank should be 0.3 c.c.; for concentrations from 1.2 to 1.8 mg. of phosphate the blank should be 0.6 c.c.

**COMBUSTION CONTROL.**

In past seasons the Boiler Committee has done work of enormous value to the whole industry in their investigations of furnace and boiler conditions. The development and improvement in steam-raising plant at the mills has been phenomenal since as recently as 1933. But I am of the opinion that the laboratory, whether through its own fault or not, has fallen far short in its contribution to these results. As I mentioned before, combustion is purely a chemical problem of oxidation, though no doubt involving many factors of a physico-chemical nature. Therefore the chemist can be of great assistance to the engineer in his efforts to supply the correct conditions for combustion by mechanical means.
One of the most obvious ways in which the laboratory should be used is for the purpose of gas analysis, and it is mainly with this subject that I propose to deal. The question of full boiler efficiency tests, and experimental variation and observation of combustion conditions, is worthy of a lengthy paper itself, and I must leave this for some later date.

**Sampling.**

Our old friend, the "fully representative sample," crops up again, and is probably more conspicuous by its absence in gas analysis than in any other of the chemists' nefarious activities. To take an Orsat lead "and he only IS subject to Alibi, place, carborunum is the time, engineer other "plumber's friends" will one can gather in the analysis subject that palladium U-tube potash, of gas efficiency CO₂ and although certain output analysis communicating be in it is desired to check the amount of air leakage and the CO₂ per sample put under a slight pressure. This guards an aspirator bottle filled with chloride solution used both in the collection of gas samples and in should be attached to the lower cock, and the gas sample is analysed. Aspirator pump is started, and when it is, distinct methyl orange red with sulphuric acid is that all air has been drawn from the sampling line, for hydrogen to appear in the flue gases also, and cases which have occurred, it is possible at times to this solution is lower than in any other of practical utility.

If it is desired to check the amount of air leakage through the setting of a boiler, the gas should be sampled high in the first pass after the furnace (using a water-cooled sampling tube), and again before entering the main flue.

Recorders of different types will have their own methods for drawing a continuous sample, but the necessity of carefully testing all lines for air leaks cannot be too strongly emphasised. A vacuum test is the most effective. Place a "bubbling bottle" in the line, close to the pump. Plug the line at the boiler end and evacuate at the pump to at least 25 ins. of mercury. If bubbles continue in the bottle, look for leaks. Few pipe joints or unions fitted in the ordinary way will stand up to this test, and the aid of red lead and other "plumber's friends" will have to be sought.

Before closing these remarks on sampling, I should like to draw attention to the very efficient methods used by J. J. Coetzee[1] in his work at the Refinery in November, 1937. A test was run by the S.A. Fuel Research Institute, to show the varying efficiency of a given boiler using different sizes and types of coal. The sampling methods were an object-lesson in themselves, and although as yet unpublished, I should urge every engineer and chemist to obtain a copy when the paper is made available by the Natal Institute of Engineers.

**Flue Gas Analysis.**

Where intermittent samples are taken, they should be brought to the laboratory and cooled to room temperature before the analysis is done. It is bad practice to take the Orsat to the job.

I shall not spend any time on a description of laboratory gas analysis methods. The use of the Orsat apparatus should be common meat to all chemists, and gas analysis in all its phases is perfectly covered in scores of standard texts.

The determinations should not always be confined to CO₂, however. It may quite well happen that incomplete combustion is taking place, and the CO estimation is necessary to detect this. From recent cases which have occurred, it is possible at times for hydrogen to appear in the flue gases also, and means should be at hand to check this percentage. Therefore I should advise all laboratories to possess a full Orsat equipment, including a slow combustion pipette, so that the complete gas analysis may be done. The method for hydrogen using palladium black is slow and difficult.
Carbon Dioxide Recorders.

Probably every engineer present will be able to recount his experiences with "CO₂ recorders that did not work." Relics of many types of these messy gadgets are spread throughout the mills along the coast, the nett result being probably lots of interesting examples of the glass-blower's art stacked in the laboratory, and a pile of spare charts lying in the store! But, surprisingly, they do work, if understood and properly looked after. First, their value must be appreciated, and, secondly, they must be put in charge of some responsible person. Admittedly, the instruments for this measurement have improved enormously in the last few years, and are now a far more practical proposition than of yore.

The recorders are of two main types, though others, of much lesser application, exist. First come the chemical absorption meters, and then those employing the thermal conductivity of gases as their working principle. Most of the meters used in the past, at any rate in this industry, have been of the former type. The Refinery has probably made as many trials as anybody, and out of the ruck emerge two instruments—the "Electroflo" absorption meter and the Geo. Kent "Multelec" CO₂ recorder.

The "Electroflo" shows improvements on most of the other absorption meters, in that it employs a large volume (3 gallons) of caustic potash solution, thus cutting down replenishments, is of comparatively robust construction, has practically no glass parts or rubber connections, and gives a fairly quick response. It is fitted with a really excellent motor-driven pump for withdrawing the gas sample, and is convenient for taking check samples. Its disadvantages are the great amount of time necessary for maintenance and care, the very close chart (thickness of pen line represents almost 0.5 per cent.) and the poor type of pen inking arrangement. The accuracy for all practical purposes is no better than 1.0 per cent.

The Kent "Multelec" Mark I CO₂ Recorder is a really outstanding instrument, and is worthy of a fairly full description. We have had one working at the Refinery all this season, and the results have been very satisfactory. The accuracy found, by careful Orsat checks, is very close to 0.1 per cent. The relative time used in care of the instrument is very small indeed, and the chart is an open one (thickness of pen line represents almost 0.5 per cent.) and the poor type of pen inking arrangement. The accuracy for all practical purposes is no better than 1.0 per cent.

The principle of working is as follows: The flue gas is drawn off by an aspirator through a carborundum primary filter. The gas then passes through the analysis cabinet, where a portion of the main stream is withdrawn at a constant rate. Now water vapour has an appreciable thermal conductivity, but instead of removing the moisture by drying, as was done in earlier instruments of this type, the subsample is saturated with water vapour at the temperature of the case, which is electrically thermostated. The measuring part of the instrument consists of two small conductivity cells. One is sealed and contains a reference gas, the other is connected to the by-passed gas stream. Both contain double platinum wires, coated with glass and held taut by a fine glass spiral. The wires are heated electrically with a constant energy input, and, as the temperature of the case is kept constant, the dissipation of the heat in the measuring cell will only vary with the amount of heat which the stream of gas is capable of taking up. This in turn will vary with the thermal conductivity of the gas. Now air, oxygen, nitrogen, and carbon monoxide have approximately equal thermal conductivities, whereas that of carbon dioxide is about half as great. So that as the percentage of CO₂ in the gas varies, more or less heat will be drawn from the platinum wire in proportion. Thus the wires in the two cells will be at different temperatures. The electrical resistance of platinum varies with the temperature, hence the altered resistance of the platinum wire in the measuring cell indicates the alteration in the gas composition.

Both the measuring cell and the reference cell are inserted as two arms of an unbalanced a.c. Wheatstone bridge, so as the gas composition varies, the out-of-balance varies. The out-of-balance e.m.f. is then measured with a "Multelec" recorder employing an a.c. potentiometer.

The a.c. supply to the whole outfit is controlled by a phase and voltage regulator, and the bridge is temperature and current compensated.

So we have here again another useful application of potentiometric recording measurements of a small e.m.f., as we met with in our pH and electrical conductivity control instruments.

A drawing of the gas circuit in the analysis cabinet is shown in Fig. III. below.

(1) Aspirator water pump.
(2) Primary carborundum filter in flue.
(3) Lead-lined pipe leading to analysis cabinet.
(4) Water seal.
(5) Secondary filter compartment.
(6) Upper compartment of gas bubbler.
(7) Lower compartment of gas bubbler, containing transformer oil.
(8) Intake of by-passed gas.
(9) Water bubbler, giving constant flow and saturating the gas.
(10) Return path of by-passed gas after leaving measuring cell.
DIAGRAM ILLUSTRATING THE GAS CIRCUIT OF THE MULTIELECO2 RECORDER.

Fig. 3.
The apparatus may sound somewhat complicated, but the principles of working are simple, and, as mentioned before, the time spent in maintenance, if regular, need be very short.

**Indications of Flue Gas Analysis.**

Interpretation of results obtained from the methods described necessitates a thorough knowledge of the chemistry of combustion. As I mentioned before, there is no space here for a dissertation on these lines, but the few notes now given may serve as an opening to some interesting discussion.

Most boiler furnaces are worked with too large an excess of air. More than the theoretical quantity of air is necessary, as otherwise it would not be possible to secure such intimate mixing of the fuel with the air that every particle of carbon would be oxidized whilst the gases were still within the zone of combustion. Another reason for excess air is the necessity to keep the furnace temperature from rising unduly.

If combustion is complete, all carbon present in the fuel should appear in the flue gases as carbon dioxide, plus, of course, the nitrogen that was present in the air used for the combustion. As excess air is essential, oxygen will also be found in the flue gases. If combustion is incomplete carbon monoxide, hydrocarbons and, possibly, hydrogen will be present in the flue gases, and theoretically oxygen should then be absent. This is where speed of the gases and furnace temperature plays an important part. In passing through the fuel the oxygen is, according to most theories, combined with the carbon to form carbon monoxide, and it is just above the fuel bed that the final conversion to the dioxide takes place; hence the necessity for secondary air. Now if the speed of the gases is too great, the monoxide may be rushed through this zone of combustion before oxidation is completed. So that it is still possible to have a large excess of air with incomplete combustion; but this possibility dwindles as furnace temperatures rise, more particularly in cases where preheated air is used.

Mixing of the gases must be good, but sufficient time for combustion must also be given. The mixing of gas streams is governed by pressure, velocity, density and the temperature of the furnace. If the mixing is incomplete, then the combustion will be incomplete. Similarly, if unburned gas strikes a cold surface it will be cooled below the temperature of combustion and will require reheating for completion of the reaction.

High carbon dioxide does not necessarily mean perfect combustion, as 1 per cent. of carbon monoxide means approximately 4.5 per cent. loss due to incomplete combustion. And a low dioxide content may be caused by insufficient air (accompanied by high monoxide), but this is almost invariably due to an excess of air. A great deal of this excess air may come through leaky boiler settings, and Coetzee (loc. cit.) shows over 60 per cent. of the total air supplied to a furnace due to leaks, leaving only 40 per cent. which came through the grate in the normal way.

Do not try to get a high CO₂ simply by cutting down the draught. A proper relation of draught, fuel, and fuel resistance is required, and it should be borne in mind that the CO₂ indicates roughly the percentage of air used to the percentage of air which has not been used.

Losses of heat through excess air above 12 per cent. CO₂ are not great, but below this figure the fall in efficiency is considerable. On the other hand, when the CO₂ rises to 14 per cent. or more, tests should certainly be made to see if any monoxide is present.

In recent designs of bagasse furnaces unusual combustion conditions may be met with, and the close study of the furnace and flue gases in this equipment is rather urgently required. In the meantime, chemists at the mills should keep careful records of what appear to be abnormal results of complete flue gas analyses. The high moisture in bagasse, its fine state of division, and high furnace temperature, may cause combustion difficulties from the point of view of peak efficiencies, which have never been dreamed of in the past.

**Conclusion.**

This paper has turned out to be rather a disjointed attempt to cover an enormous field in a totally inadequate space, but the author will feel that its purpose has been served if it simply arouses sufficient interest to open the way for closer laboratory control, and further investigations of the problems which it discusses.
The PRESIDENT, in opening the paper for discussion, said it contained many useful references. The only place where steam was raised in the South African sugar industry, which had a definite continuous control on the boiler feed, was the Refinery. This should be an incentive to the sugar factories. In one factory he had found corrosion which had created damage to the extent of about £5,000 before it was put right. The President referred to the large amounts of silt in some river waters that caused damage to the extent of about £5,000 before it was put right. The President referred to the large amounts of silt in some river waters used for boilers, which had thus had their bottoms bulged, their tubes burst, and in some of the others there had been corrosion at the feed inlet and at the orifice where the steam was measured. It was time this neglect was attended to. He referred to Mr. Hayes' statement that "losses of heat through excess air above 12 per cent. CO₂ are not great, but below this figure the fall in efficiency is considerable. On the other hand, when the CO₂ rises to 14 per cent. or more, tests should certainly be made to see if any monoxide is present." He said with bagasse as against coal a very much higher CO₂ content was observable. He had found it quite easy to get tests of 13 to 14 per cent. of CO₂ with bagasse under favourable conditions, taking CO₂ near the entrance of the boiler. He hoped, in conclusion, that chemists and engineers would make a study of this paper.

Mr. BECHARD suggested that the paper should come before the Technologists' Association again when there was a better attendance of engineers, so that it could be more ably discussed.

Mr. McNicol stated that, as an engineer, he fully appreciated the assistance of the chemist in the betterment of boiler conditions in and applied to the industry. The chemistry of boiler work and control was an admitted factor in every power station of any size in the world. The chemist was essential in taking care of the various instruments in a factory such as automatic pH control and CO₂ recording instruments. Mr. Hayes took great care of his instruments. Regarding the supply of boilers, Mr. McNicol said that it was far better to state some definite rate of evaporation required of a boiler when ordering one. Unless the industry told the boiler maker what he required, how could the boiler maker know what to supply? Boilers should be supplied with a guaranteed rate per hour at a guaranteed efficiency. Mr. McNicol said they were to-day offering the industry a continuous blow-down system, and so one could blow down exactly the proportion of boiler water that was required from an analysis. In continuous blowing down there was no continuous loss of heat, as that was taken care of in the flash vessels, and returned back to the low-pressure steam. Mr. McNicol went on to say that a great deal of work on embrittlement had been done on the Rand, and the sugar industry should study the results obtained.

Mr. RISHWORTH said that modern power station equipment all included pre-water evaporators. Were they of any benefit in the sugar industry, or was the quantity of feed water involved too small?

Mr. WILSON welcomed Mr. Hayes paper, and praised his painstaking work. Replying to Mr. McNicol, he said that it was now the general tendency in ordering boilers to specify the output required, and not the heating surface or the com-
bustion space in relation to the heating surface. The proper figures regarding fuel and the nature of the feed water to be supplied to those boilers must also be given. The Refinery was the only place with an up-to-date filtration plant for feed water treatment. They wanted to improve still further and soften their water, and incorporated with that would be a continuous blow-down system, which would keep a check on the amount of solids in the boiler feed water.

Mr. WICKES, in praising Mr. Hayes' work, suggested that he should be placed on the Boiler Committee.

Mr. ARDINGTON said that he recognised great room for improvement in boiler practice in the industry. He hoped Mr. Hayes' paper would stimulate interest in boiler control work.

Mr. HAYES, replying, thanked the speakers for their appreciation of his paper. In connection with Dr. Hedley's remarks on the high CO₂ obtainable with bagasse furnaces, he said that it was well recognised that, owing to the nature of bagasse fuel, and its finely divided condition, it was possible to work with a much smaller amount of excess air than with a coal fire. Nevertheless it was still advisable, when a high CO₂ was recorded, to test carefully for the presence of CO, to check the high losses occasioned by incomplete combustion.

A case had come to his notice recently where a thermal conductivity CO₂ recorder had behaved erratically, showing first a high percentage and then zero. He had diagnosed this as being due to free hydrogen, which theory subsequently proved correct; but if a full gas analysis had been done in the first instance it would have clearly shown up the incomplete combustion due to a deficiency of air.

Replying to Mr. Rishworth's query about evaporators, he said that their economical installation required an investigation of the conditions under which each individual plant operated, but that even when condensate only was used for feed, the water would still require a certain amount of conditioning and the same careful control.

To Mr. McNicol, he said that he fully realised that a great deal of research on boiler problems had already been carried out in this country, but that more was required in the Natal sugar industry. If once started there would be many people to assist, and he was quite sure the South African Fuel Research Institute would co-operate gladly.

The PRESIDENT, referring to Mr. Bechard's remark, said he thought it might be possible to have the paper read to the Institute of Engineers. With regard to Mr. McNicol's request for a specification of output of the boilers, when the boilers on test were started it was never believed that 6 lbs. per square foot could be obtained from the boilers when burning bagasse, now everyone knew it could be done. The Refinery, he went on to say, were the people who did more to control their water than anybody else, and yet they wanted to improve still further, thereby setting a magnificent example to the industry. He concluded by asking for a hearty vote of thanks to be extended to Mr. Hayes for his paper.