

THE PROTECTION OF BOILERS FROM SUGAR CONTAMINATION IN FEEDWATER

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Abstract

Sugar contamination of boiler feedwater by small continuous traces is not as serious as that from large 'slugs' which frequently find their way into the boilers. Reference is made to several incidents of sugar contamination in boilers to show that the most common causes are a malfunction of the feedwater system or its mismanagement, and to show that the method of sugar detection is seldom at fault. Some of the devices for detecting sugar traces in use or proposed are mentioned and their relative merits are discussed. In particular, the apparatus which was recently evaluated at the Sugar Milling Research Institute (SMRI) is discussed in some detail and test results are given. The apparatus was designed to measure the change in pH and conductivity of a condensate after being heated to 265°C for a few minutes. Suggestions are given on the type of monitor to be used in raw and refined sugar operations, the design and operation of the condensate handling system, and the options available for the future. It is concluded that, subject to some important precautions, the conductivity monitoring method is satisfactory for protecting boilers in a raw sugar mill against catastrophic failure.

Introduction

Traces of sugar in boiler feedwater up to some arbitrary level, possibly as high as 50 parts per million (ppm), are believed to be quite safe for the performance and safety of boilers, provided the chemical treatment of feedwater is adequate. However the occasional heavy slugs of sugar which find their way into the feedwater system can be very dangerous and it is these high doses which need to be eliminated by an effective sugar monitoring system to protect the boilers.

In recent years the SMRI has received many queries on the methods and procedures used to monitor the sugar content of condensates intended for boiler feedwater. Much has been written and researched on this subject yet there are still several unanswered questions, for example:

- What is the real effect of traces of sugar in boiler feedwater and what costs are involved?
- What level of sugar contamination is acceptable?
- What method of detecting sugar in condensates is best suited for the protection of boilers?

Most engineers would be prepared to spend large sums of capital and maintenance money to be able to accurately measure the contamination down to levels of perhaps 20 ppm. This is justified on the basis of the very high costs incurred in boiler down time, repair and maintenance caused either directly or indirectly by sugar contamination. However these high costs are incurred only when sugar contamination is excessive and undetected. For boiler safety it is preferable to detect high levels of sugar contamination with absolute certainty than to expend great effort on the accurate measurement of small traces.

Experiences of sugar in boilers

General

There have been many incidents of sugar contamination in boilers since the sugar industry began to use steam. Most of the recent experiences of this phenomenon in South Africa have not been catastrophic, and the boilers have survived with little or no permanent damage.

Usually the incident starts with undetected entrainment or leakage of sugar into condensate, which eventually reveals itself by the characteristic smell of caramel emanating from steam drains. The pH in the boiler falls sharply and must be controlled by slug dosing caustic soda into the feedwater. If the pH responds to this control the boilers can be kept on line, provided an adequate supply of uncontaminated feedwater is available.

The following is a brief list of the causes and effects of some of the incidents which have come to the writers' attention:

- A welding glove left in a juice line caused one effect of the evaporator to fill up and overflow into the calandria of the next vessel. Several hours of production were lost but there was no permanent damage
- Failure of the juice level control in an evaporator caused juice to fill the vessel to the vapour outlet and flow through the condensate system into the boiler feedwater tank. Four days of production were lost
- Several boiler shut downs have been caused by failure of juice heater tubes
- Extensive tube leaks in a B pan caused sugar to reach the boilers three times in one season
- Rejected condensate overflowed from a sweetwater tank back into the feedwater tank and eventually entered the boilers
- The Kestner separator outlet became choked with scale, which caused juice to flow into the vapour line and then into the boiler feedwater tank
- Excessive dumping was too much for the 'reject' piping and backflow entered the boiler feedwater tank.

These may be regarded as typical for the sugar industry, and many engineers will recall similar experiences in their mills. The most important effect of these incidents was the severe loss of production and consequent financial losses, but in no instance was there permanent damage to the boilers.

In all of these incidents and in many others not recorded, the amount of sugar contamination was very high, and for different reasons was not detected by the conductivity monitoring system. In all cases however the reasons were not related to the type of monitor but to failures in the system such as dirty electrodes, poor electrical contacts, faulty valves, blocked pipes, or poor design of the dumping system.

Effects of sugar in boilers

Sucrose breaks down at high temperature into organic acids, which lower the pH and cause an increase in con-

ductivity. This results in corrosion or excessive use of sodium hydroxide, and ultimately increases the total dissolved solids.

The high temperature heating apparatus tested at the SMRI and described below has provided a means of estimating the expected pH change in relation to the sugar content of a solution when heated to above 265°C. This is shown in Figure 1. At a sucrose concentration of 50 ppm it was found that the pH could be expected to drop from 11,0 (which is the required level for boiler operation) by approximately 2,9 units. For a boiler house with a total evaporation rate of 150 t/h of steam the cost of caustic soda required to restore the pH to 11,0 is negligible compared with the loss of sugar.

If the presence of an excessive amount (i.e. > 200 ppm) of sugar in the boiler is not detected and dealt with, it can cause foaming, carry-over and fouling of strainers, steam traps, control valves, turbine blades, etc. which can result in very expensive repairs. In addition the evaporation process causes carbonaceous deposits in the boiler drum and on heating surfaces which reduce heat transfer, and could cause blockages and corrosion. It is in these areas that effective boiler water treatment is essential.

The literature researched so far has not revealed any firm recommendation for the maximum sugar contamination permitted in boilers in a sugar mill. It is suggested that a fairly high level, of the order of 20 ppm, can be tolerated by a boiler for long periods provided sufficient caustic soda is added to maintain the pH at the accepted level of 11,0 and the water treatment chemicals are carefully controlled.

Sugar detection apparatus

Several devices for the continuous monitoring of sugar contamination have been proposed and several have been tested or used with success in sugar mills. A description of these instruments follows.

Heating apparatus causing change in conductivity

In 1986 the SMRI carried out experiments to test the theory that when a sucrose solution is heated to 265°C for several minutes, there is a change in both pH and conductivity proportional to the sucrose content. The idea was based on a Japanese paper (Takatori *et al.*, 1975) in which experiments were carried out to test the theory. It was expected that an instrument could be designed around this principle and used to continuously monitor sugar traces in condensates.

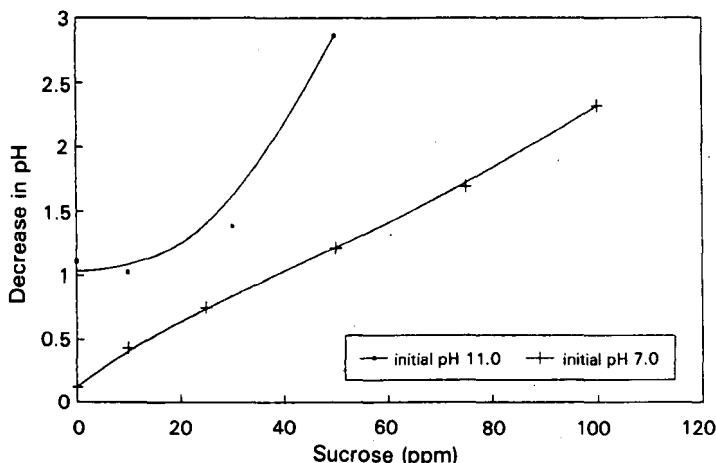


FIGURE 1 Decrease in pH from static tests.

The first version of the apparatus comprised a sampling system, which commenced with a filter, followed by a combined conductivity/pH cell and a high pressure pump that passed the sample through a stainless steel coil contained in a small thermostatically controlled oven. The sample was then cooled in a coil in a water bath, after which it passed through a pressure reducing valve and then into a second combined conductivity/pH cell.

Preliminary experiments were carried out to determine the best residence time by sealing a small sample in the heating tube and raising its temperature to 265°C for different periods up to 100 minutes. It was found that there was a linear relationship between change in conductivity and residence time up to the first 50 minutes and a tendency to level off with longer times (see Figure 2). The tests continued with a residence time of 20 minutes to find the effect of sucrose concentration on pH starting from a neutral solution and from a solution initially at a pH of 11,0. The results of these tests are shown in Figure 1.

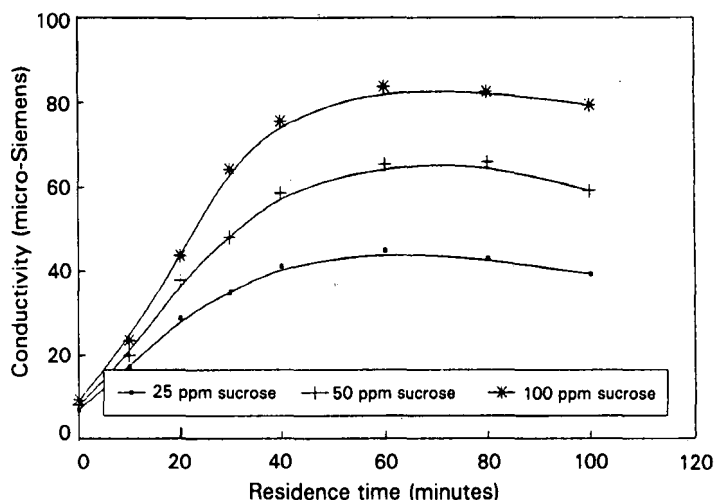


FIGURE 2 Conductivity vs time.

The pH change from neutral with sucrose concentrations in the range 0 to 120 ppm is a fairly flat curve, whereas that from pH 11,0 follows a steeper curve, the shape of which is difficult to explain. The major difference was that caustic soda was used to raise the initial pH to 11,0. At zero sucrose concentration the pH change was over one unit which could possibly be attributed to carbon dioxide absorption during heating.

During these experiments it was found that the oven temperature control was erratic and heating was then carried out in an oil bath. The fumes from the oil bath were however troublesome and a third heating method was used, in which three electric heating elements, each of 300 watt, were attached to a straight 400 mm length of 6 mm diameter stainless steel tube and enclosed in an insulated housing. This heater worked well but the electrical connections were not very secure because of the small dimensions and high temperature.

A diagram of the apparatus in its final form is shown in Figure 3. The sample was pumped at 8 MPa at a flow of 0,55 l/hr, and heated to 270°C. The overall residence time of the sample was 2,5 minutes. Various safety devices were incorporated as follows:

- A pressure switch to cut out the heater if the pressure dropped below 7 MPa

- A heat-sensitive fuse built into the heater to fail at about 400°C
- A thermocouple arranged to trip the heater if the cooling water outlet temperature exceeded 40°C
- A flow detector on the cooling water to trip the heater if the cooling water flow dropped below a pre-set limit
- An interlock between the heater and pump motor so that the heater could not operate while the pump was off.

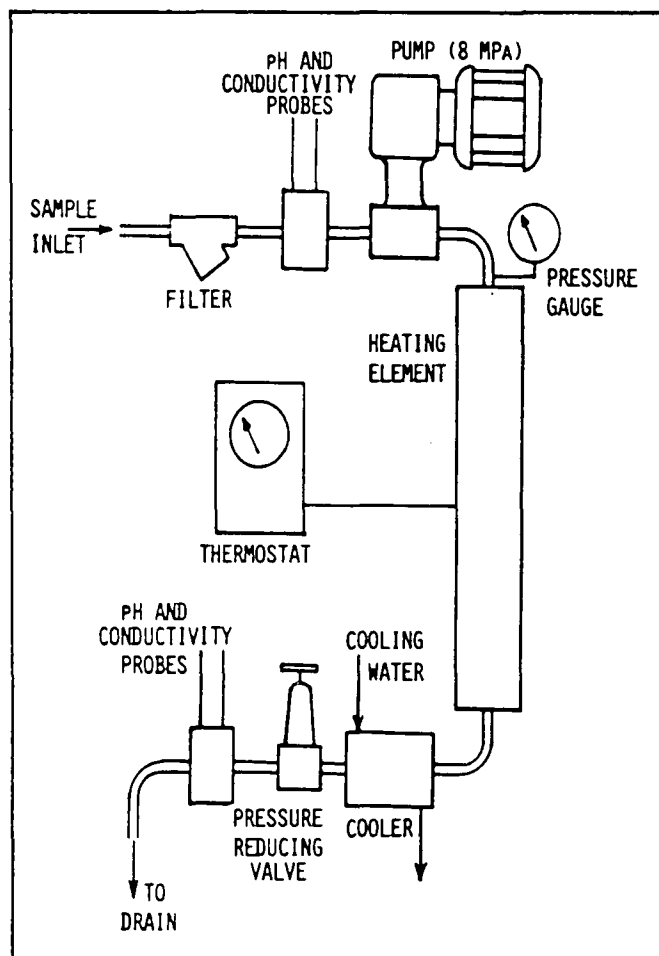


FIGURE 3 Diagram of the apparatus for determining sugar traces.

After some difficulties the apparatus was successfully tested as a continuous sampler and a definite relationship between conductivity and sucrose content was measured (See Figure 4).

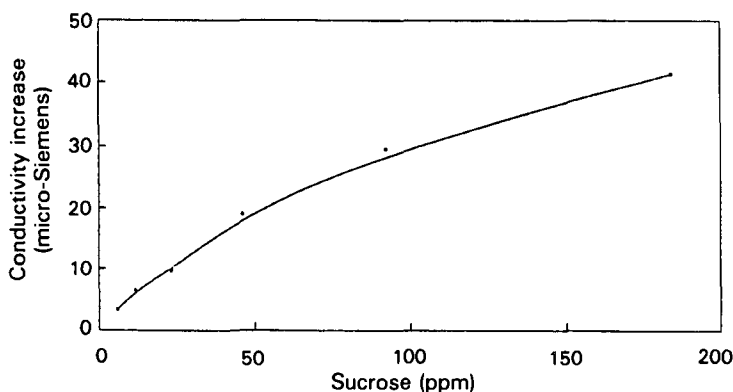


FIGURE 4 Conductivity increase using continuous apparatus.

However the various components of the apparatus were fragile and failed frequently. The worst problems were associated with the pump seals, pressure switch and heaters. It was also evident that the tube was being contaminated with scale and frequent cleaning was necessary to ensure good repeatability. The relatively long reaction time (three to five minutes) was also believed to be a disadvantage. The apparatus was therefore considered unsuitable as a factory-based continuous sugar trace measuring device and was dismantled.

Total organic carbon

The principle of this instrument is the conversion of organic carbon to carbon dioxide by irradiation with ultra-violet light after addition of persulphate. The quantity of carbon dioxide is measured by means of an infrared detector and the output signal is proportional to the organic content of the sample.

The apparatus has been locally modified and improved by the Watertech Division of the Council for Scientific and Industrial Research (CSIR) and is now commercially available at about R30 000. It has not yet been tested in a sugar mill environment, but is claimed to be robust and reliable enough to survive in any industrial application. Reaction time could be reduced to about one minute per sample stream, depending on the accuracy required.

Auto-analyser

In this apparatus water samples containing trace amounts of sugar are pumped into a manifold where mixing with the reagents (resorcinol/hydrochloric acid) occurs. The mixture is then continuously pumped into a heating bath where colour development occurs. The colour, which is proportional to the sugar content, is measured in a colorimeter. An advantage over other designs is that the reaction is sugar specific. A disadvantage is that the reaction time can vary from 5 to 15 minutes, depending on the reagents used and the accuracy required.

Auto-analysers have been used successfully to monitor condensates for boiler feed, and descriptions of two types of auto-analyser used in monitoring refinery wastewaters are given by Fowler (1977). Schäffler (1978) described the use of an auto-analyser for monitoring entrainment. Continuous use of the instrument in the factory environment in this case was not very successful.

Auto-analysers have worked well in a clean laboratory where supervision is good, but they are not suited to on-line monitoring in the harsh factory environment.

The 'Spaldinlab Sugar-Tektor' using three reagents

This device is described by Parker and Bond (1958) and Bruijn (1962). It is essentially an auto-analyser measuring colour developed in the reaction with triphenyl tetrazolium-chloride (TTC). The instrument uses two other reagents, sodium hydroxide and hydrochloric acid, and requires a small gas burner to provide the source of heat for reaction. The reaction time is approximately 15 minutes.

The instrument is commercially available through British Sugar Corp. The SMRI tested a version of the instrument (constructed in the SMRI workshop) at Hulett Refineries in 1961 and described it as reliable. However the long reaction time is a distinct disadvantage.

Pulsed amperometric detector (PAD)

This instrument measures the organic content of a solution by detecting the current flowing between two electrodes immediately after application of a predetermined potential. After the detection phase, two short cleaning pulses are applied to the electrodes to remove substances plated onto them. The procedure is extremely sensitive and detection is instantaneous.

This principle was tested at the SMRI both as a stand-alone unit and as part of a high performance liquid chromatography installation. Unfortunately an impurity present in factory samples interfered with sugar analysis (Morel du Boil, 1989), detracting from its use as a sucrose detector and further work was discontinued.

Flame photometer

Flame photometers have been in use at several sugar mills for many years and have worked well provided they have been well maintained and serviced. The use of a flame photometer for monitoring entrainment was described by Dale and Lamusse (1977). However the instrument does not detect sucrose directly but measures the concentration of potassium ions that are assumed always to be present with the sugar. For this reason they are considered to be only slightly better than conductivity monitors.

Conductivity monitors

In South Africa the use of conductivity monitors as described by Cargill (1962) and Douglas (1962) has become almost universal, even though it is appreciated that the conductivity of a solution is an imperfect measure of the sugar content. The suitability of such a monitor depends on the presence of other impurities in the form of various salts which always accompany the sugar. The relationship between sucrose content and conductivity is highly variable because it depends on the nature and quantity of these salts. This in turn depends on the source of the contamination and on the constituents of the cane, which can vary throughout the season.

The industrial type of multi-channel conductivity monitor with multiple outputs for recording, indicating or triggering alarms has been commercially available for many years and some models have proved very reliable.

In a typical raw sugar mill the conductivity monitoring system can be made to work satisfactorily as a sugar detector provided it is properly designed and installed and well maintained. The most important point is that the conductivity method will certainly react to gross contamination of hundreds of ppm and higher, and it is these incidents which place the boilers in the greatest danger.

The inherent inaccuracy of the monitors could result in momentary undetected sugar contamination of boiler feed-water of perhaps 50 ppm, which may sound excessive but will not result in any serious problem in the boilers provided the chemical treatment is carefully monitored and the pH and total dissolved solids are well controlled.

Recommendations

System design

With the correct design of condensate storage and handling systems, the level of sugar contamination can be controlled to a reasonable level. In particular, the exhaust condensate from the calandria of the first effect is most probably uncontaminated and should comprise at least 75% of the total boiler requirement. The maximum level of con-

tamination of the other condensates as detected by a conductivity monitor may be as high as 50 ppm before the monitor reacts and dumps the offending stream, but the mixture of these condensates would then end up with about 13 ppm of contamination, which is believed to be completely safe. In any event experience with conductivity monitors has shown that the usual level that can be easily detected is actually much lower than 50 ppm.

Some recommendations to be incorporated into the design, specification and operation of a condensate handling system to meet the above requirements are provided in the Appendix.

Refinery condensates

The special case of contamination of condensates by refined sugar should be mentioned. Refined sugar contains insufficient salts to trigger a conductivity monitor. In the case of a refinery attached to a raw sugar mill, there should be sufficient condensate from the raw house to meet the needs of the boilers without using any refinery pan condensate. An independent refinery would have to consider one of the alternative detectors listed above which more specifically measure sugar contamination. The most promising of these appears to be the total organic carbon analyser which can be obtained and serviced locally. In this case the initial cost and operating expenses would be justified.

Future possibilities

Computer surveillance

There is much to be gained from the incorporation of a surveillance computer for the condensate handling system. This could take the form of a PC or microprocessor programmed to expect certain signals from the monitors, flowmeters, valves, tank level indicators and controls, and other components. It would also expect the manual sampling valves to be operated every hour and the conductivity electrodes to be checked and recalibrated at regular intervals. It could even be arranged to carry out the physical recalibration of electrodes at pre-determined intervals. As soon as none of these events takes place, or when anything strange occurs, it will trigger the alarm and the engineer can be notified.

Laboratory analysis

At each sugar mill the laboratory has the task of routine hourly sampling and analysis of condensates. The installation of a continuous analyser in the laboratory would be an effective means of eliminating this drudgery and saving labour. The reaction time of this instrument would at least be better than sampling all streams once per hour, and it would be an effective backup to the conductivity monitoring system. It would of course require all condensate streams to be piped to the laboratory or a suitable room in the factory. The important point is that the analyser would operate in a laboratory environment, and would therefore be expected to perform satisfactorily provided supervisory control was introduced.

Conclusions

The boilers in a raw sugar mill can be effectively protected from the effects of sugar contamination by using a properly designed and installed condensate handling system in which the sugar is detected by a good conductivity monitoring instrument. The following features and precautions are important for efficient operation:

- The system should be designed to include all possible contingencies

- Adequate storage should be provided for uncontaminated condensate
- Operation and maintenance should be well managed
- Regular inspection and testing of the system is necessary to ensure that alarms and failsafe procedures are effective
- Procedures should be adequately documented and all staff thoroughly trained.

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APPENDIX

Recommendations for an effective condensate handling system

- Condensates returning to the boiler feed tanks should be given priority dependent on their expected extent of contamination and hence their suitability for boiler feed. Thus exhaust condensate from the first evap-

orator effect would have highest priority, and vapour condensates from later effects a lower priority. Juice heater condensates are generally suspect because even small leaks in juice heater tubes will enter the condensate due to the pressure differential. They are therefore not recommended for boiler feedwater purposes.

- All piping from these different sources should be brought to the same point so that monitoring can be carried out at one central point.
- Each pipe should be provided with a separate conductivity monitor and associated dump valve.
- The accepted condensate pipes into the boiler feedwater tank should be provided with further conductivity monitors and dump valves so that all condensates are monitored twice on the way to the boilers.
- Dump valves should be arranged to discharge rejected condensate directly into the reject tank with no possibility of the outlets becoming blocked or choked.
- All dump valves should be provided with a positive indication of their position. This indication should be displayed at the control panel.
- The control system should be arranged so that high priority condensates are the last to overflow to the sweetwater tank.
- The sweetwater tank should be sited so that there is no possibility of contaminating the feedwater in the event of an overflow.
- The conductivity monitors should be regularly checked by competent staff. At least once per shift the set point should be set down until the dump valve operates, and the operation should be carefully observed to ensure that there is no problem. The conductivity reading at this point should be recorded in a log book and a sample should be taken to the laboratory to be checked. The set point is then reset to a level which is established by the engineer from time to time.
- A bulk storage tank with a capacity of at least three hours at full steaming rate should be provided and arranged so that it can be kept full and the water used continuously from it during normal operation.
- A control panel should be provided in a position, say boiler control room, where it is continuously supervised. The panel should indicate the conductivity reading and dump valve position of every stream as well as the various tank levels. Alarms should be provided to sound when any set point is exceeded and when any dump valve operates. Low tank levels should also sound alarms according to the system's demands.