Water Technologies & Solutions
application note

How total organic carbon (TOC) monitoring enables sugar mills to close the metrology gap and minimize revenue loss

summary

application – Leak detection

technology – Total Organic Carbon (TOC) analysis

comparison factors – accuracy and sensitivity of detecting organic contamination in water

results – TOC analysis demonstrated superior accuracy and sensitivity when compared with water quality parameters commonly used today

keywords – F&B, sugar, organics monitoring, leak detection, conductivity, pH, redox potential, Sievers* InnovOx TOC, condensate, cost, product loss

background

Sugar manufacturing is an extremely water-intensive process in which almost every single unit of operation requires water. For instance, water must be sprayed on sugarcanes during the milling process to maximize juice extraction. The mills themselves are driven by steam turbines, and for every two tons of sugarcane milled, one metric ton of steam is consumed. Further purification and crystallization of the molasses are also carried out using steam-driven machinery. Therefore, it should come as no surprise that sugar manufacturers, especially those located in areas facing high water stress, will find every possible means to conserve and reuse water.

One available strategy for water reuse is to capture and condense steam exhaust from boilers and other processing equipment. However, before this condensate is reused, it is common practice to utilize its high temperature as an economical way to heat separate fluid streams, such as extracted cane juice or molasses for further processing. This can be achieved via heat exchanger equipment, while preventing physical mixing of the two streams. Thereafter, the cooled condensate often undergoes some polishing treatment before being reused as process makeup or even feedwater for the boiler systems, allowing sugar manufacturers to save on both heat and water.

challenge

In actual practice, some degree of non-ideal performance within a heat exchanger is to be expected, especially after prolonged and repeated operation. Metal fatigue and corrosion will take their toll, and consequently, pinholes can develop in the metal surfaces separating the two fluid streams, allowing for leaks to happen bilaterally.

For sugar manufacturers, this breach in the physical barrier can cause a multitude of problems. First and foremost, there exists a loss of product if extracted juice or molasses leaks into the condensate as it passes through the heat exchanger. While these losses may seem trivial, they may accrue to a substantial amount of unrealized revenue over time. Consider the following example:

- A typical mill produces between 300,000 – 400,000 metric tons of raw sugar annually
- As much as 0.1% of product is lost due to mechanical factors[1] equating to 300 to 400 tons of lost product
- Assuming an average selling price of $400 USD per ton, this translates to revenue loss of $120 ~ 160K USD per year

Additionally, such leaks simultaneously contaminate the condensate. In these scenarios, sugar manufacturers must consume additional time and resources to treat the condensate before it can be reused, assuming it is economically viable to do so. Otherwise, manufacturers may be compelled to send the condensate to waste, resulting in a loss of opportunity to conserve water, and higher treatment costs of the contaminated water prior to discharge.

Early detection of leaks is critical to avoiding unnecessary product loss and limiting the extent of equipment damage. As data subsequently presented will demonstrate, existing methods used to monitor condensate quality may fail completely at detecting organic impurities in a timely manner. Should an unsuspecting process owner then continue to reuse compromised condensate, the risks will be even more severe. For example, if the compromised condensate is sent back as boiler feedwater, the impurities present in the water may be oxidized at the elevated temperatures and form organic acids, causing the pH within the boiler to fall to dangerous levels that will necessitate unplanned blowdowns. Even without these acute problems, organic contamination can increase the risk of corrosion and solid deposition within the boiler in the long run and decrease the operational lifespan of this capital asset. Expensive or prolonged repairs, and ultimately plant shutdowns may be necessary just to restore the boiler to a serviceable condition.

solution

Since there is a high chance that a heat exchanger leak will introduce organic contamination into the condensate (e.g., extracted sugarcane juice, molasses, fuel oil for the boilers, etc.), it is important to use an analytical method that can quickly detect these contaminants. Conventional water quality parameters such as pH and conductivity may struggle to detect the presence of these substances as most, if not all of the organic contaminants, do not ionize in water, and can in fact be pH-neutral. On the contrary, total organic carbon (TOC) analysis accurately measures the concentration of all covalently bonded carbon compounds in a water sample, and provides a direct indication of the organic content in the condensate at any moment. TOC analysis is also quick and quantitative, therefore enabling sugar manufacturers to make real-time, data-driven process decisions to effectively manage condensate reuse and disposition.

To demonstrate TOC analysis sensitivity for organic contamination, a laboratory study was carried out by first spiking actual condensate samples with potential contaminants. These contaminants are intermediate sugar products receiving thermal energy from hot condensate via heat exchanger equipment within an operating sugar mill. The intermediates chosen for the study are 'Supply juice' and 'EFFET A liquor', and their spike concentrations range from 50 to ~500 ppm (mg/L).

The spiked condensate, heated to 40 ± 2 degree Celsius to simulate the typical operating condition in a sugar mill, was then measured using a Sievers InnovOx Laboratory TOC Analyzer (**Figure 1**), which deploys a unique Super Critical Water Oxidation (SCWO) technology to detect organic carbon concentration ranging from 50 ppb (µg/L) to 50,000 ppm (mg/L). In addition to TOC, the conductivity, oxidation reduction potential (also known as ORP or redox potential), and pH of the spiked condensate samples were also determined.

Figure 1. Sievers* InnovOx Laboratory TOC Analyzer used to measure the spiked condensate samples

The data for each parameter (TOC, conductivity, redox potential, and pH) was subsequently analyzed against the respective spike concentrations of the two different contaminants, as shown in Figures 2-5. By considering the linearity and gradient of the correlation, further insight into the responsiveness and sensitivity of these water quality indices may be derived.

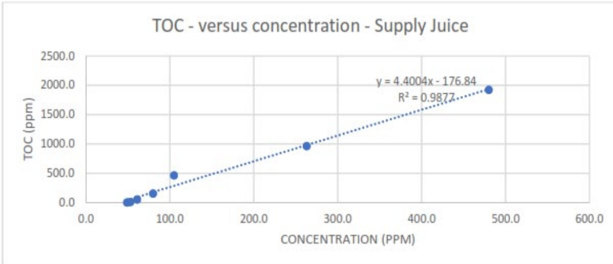

Figure 2a. Measured TOC in response to different spike concentrations of Supply juice

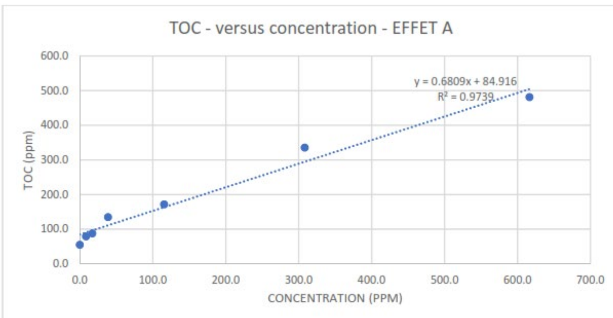

Figure 2b. Measured TOC in response to different spike concentrations of EFFET A liquor

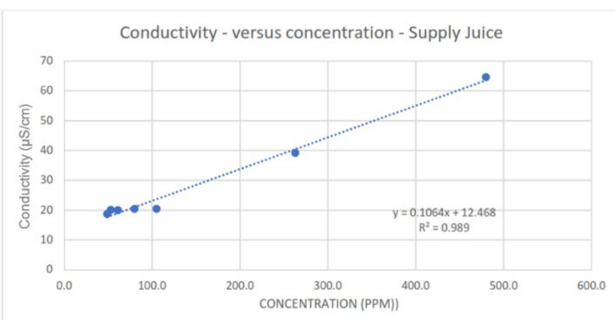

Figure 3a. Measured conductivity in response to different spike concentrations of Supply juice

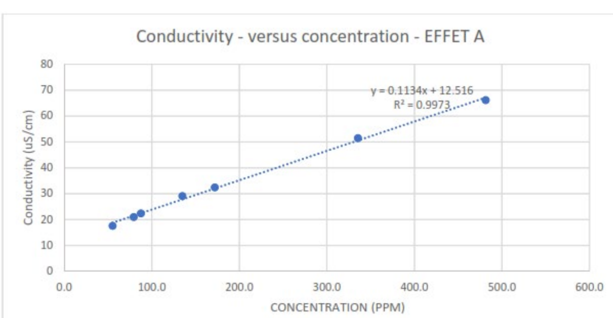

Figure 3b. Measured conductivity in response to different spike concentrations of EFFET A liquor

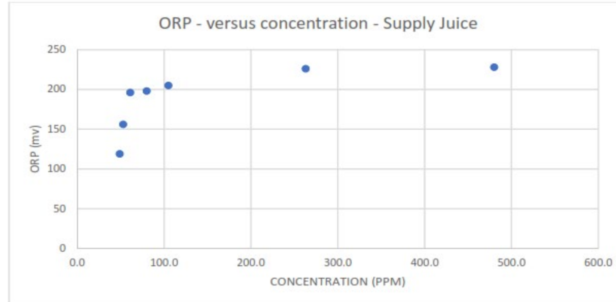

Figure 4a. Measured redox potential in response to different spike concentrations of Supply juice

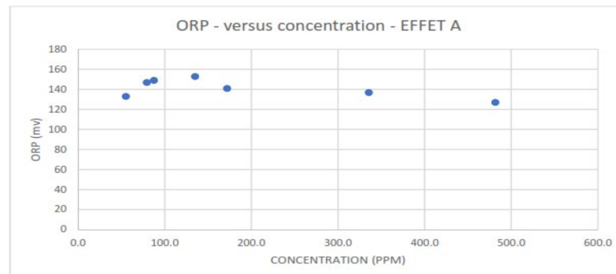

Figure 4b. Measured redox potential in response to different spike concentrations of EFFET A liquor

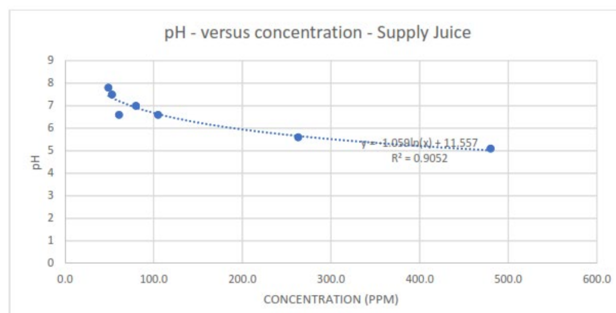

Figure 5a. Measured pH in response to different spike concentrations of Supply juice

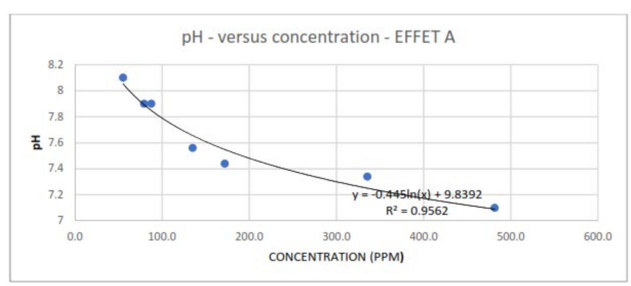

Figure 5b. Measured pH in response to different spike concentrations of EFFET A liquor

The study found that regardless of the contaminant type, TOC measurements demonstrated excellent linearity with changing spike concentrations. The slope of the correlations also showed that TOC responded with a high degree of sensitivity across the entire spike concentration range.

On the other hand, while conductivity exhibited generally good correlations for both contaminants, somewhat poorer linearity is seen at lower spike concentrations of Supply juice compared to the overall dataset (**Figure 6**). The measurements also appear to fall short in terms of sensitivity (i.e., the relatively low gradient of the correlations means that small differences in conductivity readings may easily be overlooked as process noise or be attributed to measurement uncertainty intrinsic to the conductivity sensor/probe.)

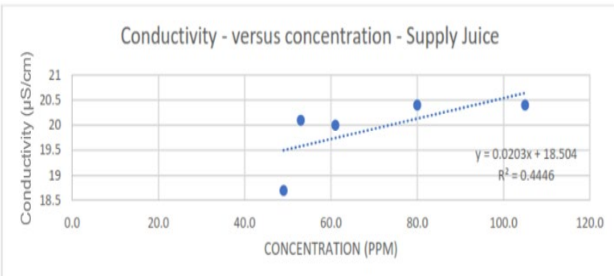

Figure 6. Poorer linearity of conductivity correlation at lower spike concentrations of Supply juice

In contrast with TOC and conductivity, there was limited success in establishing linear correlations for redox potential. In the condensate spiked with Supply juice, redox measurements showed marginal linearity at spike concentrations below 100 ppm but plateaued beyond this threshold. When challenged with the EFFET A liquor contaminant, redox measurements became incoherent despite increasing contaminant concentrations, indicating the absence of a cause-and-effect relationship.

Likewise, it was not possible to find a linear correlation between the pH of the condensate and the spike concentration of the contaminant. In fact, the measurements could only be fitted to a logarithmic function, highlighting the lack of sensitivity, and practicality, of relying on pH readings to detect the presence of organic contamination in the condensate.

conclusion

Monitoring the quality of condensate, particularly across heat exchanger equipment, is essential for sugar manufacturers who are aiming to safeguard against product and revenue loss. Similarly, it is important to verify the cleanliness of condensate targeted for reuse in order to protect critical equipment from the threat posed by contaminated condensate.

The water quality parameters commonly used today, including conductivity, redox potential and pH, may excel at detecting ionic impurities, but their limitations when addressing organic contamination are significant, especially when the contaminant is present at low concentrations. Depending solely on these indices for condensate quality monitoring can result in reduced process visibility, and consequently flawed decisions that may end up inflating production costs or damaging equipment.

TOC analysis provides a quick, accurate and sensitive means to detect the presence of organic contamination and is a valuable tool for ensuring condensate quality. Utilizing online TOC monitoring at critical steps in the process bolsters the ability of sugar mills to detect leaks that could otherwise result in equipment damage and costly production losses.

references

1. Quantification of Sugar Content Loss in various Byproducts of the Sugar Industry, *International Journal of Advance Industrial Engineering*, Vol. 3, No. 2 (June 2015)