UV-Vis Spectrophotometry

A sweet assist from spectrophotometry

For industrial sugar producers, the ability to discern the purity of their product is essential to business. Gary Bailey of American Crystal Sugar explains how visible and UV-visible spectrophotometry provides the data needed to ensure his company's products make the grade.

Gary Bailey, Quality Analyst
American Crystal Sugar

Introduction

According to the US Department of Agriculture, approximately 55 to 60 percent of domestically produced sugar comes from sugar beets. These beets are grown in a range that stretches across the northern great plains Michigan to Oregon. The sugar beets must be processed to extract and purify the sucrose contained within them. Producers such as American Crystal Sugar Company undertake this task on an industrial scale.

Refined sugar varies in color from dull brown to bright white, but the gradient of the color change is often too subtle and gradual for the naked eye to see. During the refinement process, these color differences must be detected and treated accordingly. The most frequent means of color testing involves the use of a spectrophotometer. With their rapid response and ease of use, spectrophotometers provide immediate feedback that allows for real-time adjustments to the refinement process. These adjustments can potentially save a sugar production facility significant amounts of time and money.

Challenges

The agricultural cooperative American Crystal Sugar Company is one of the largest sugar beet producers in the United States. The company is based in the Red River Valley of Minnesota and North Dakota, with scores of farmers growing produce to supply five different processing plants. The natural diversity across the crops presents ongoing challenges to a company seeking to produce a consistent, high-quality product. Gary Bailey, Quality Analyst for American Crystal Sugar, is the person tasked with monitoring the refinement process and ensuring that the final sugar product achieves all necessary standards, regardless of the variations within the starting material.

Quality checks begin soon after the source beets enter the processing plant and continue throughout the extraction and refinement process. Extraction of sugars from the beets begins when the beets are sliced and soaked in water. The sucrose dissolves out of the vegetable matter and into the water, creating a solution known as "raw juice." Raw juice contains numerous unwanted components in addition to the desired sugar. To determine the best procedure moving forward, samples of raw juice must be tested. A UV-visible spectrophotometer is the ideal tool for this task.

The starting juice is purified through several steps, with unwanted solids (dirt, beet pulp, etc.) being removed before excess water is evaporated away in stages. The increasingly pure and concentrated solutions are referred to by names such as thin juice, thick juice, or high green juice, depending on their consistency and color. At every step along the way, each juice is tested for purity and color value.

Near the conclusion of the process, the concentrated solution is boiled in a large pan to crystallize the sugar. At this point, a significant amount of the 'mother liquor' is still present amongst the sugar. The solution is transferred into a centrifuge; subsequently, the denser sugar particles are forced to the bottom of the mixture while the liquid and its dissolved impurities is drained away to eventually become molasses. The solids that are collected in the centrifuge are 99 percent pure crystal sugar.

The newly crystallized sugar and the molasses each get tested. "We do a color test on the production line every hour," Bailey reported. "So that's at least 24 times a day." The sugar all along the production line is tested multiple times per day. Every batch of finished sugar undergoes testing as it is placed into a silo for storage. Whenever sugar is removed from the silo, it is tested again. Every rail car of sugar that ships out from a processing plant is tested for color. Bagged products are also tested regularly.

Processing plants run 24 hours per day, 7 days per week; shipping samples to a lab for testing would be highly impractical. A sturdy, dependable analytical instrument is essential in such a demanding environment. Any device must also be easy to use by on-site workers and provide a rapid turnaround of results. Another key requirement is standardization across instruments; multiple devices of the same model are used across multiple plants, and all are tasked with creating a consistent product. No matter what analytical instrument is used, the company must have confidence in the uniformity of test methods and results.

Methods and motivations

Sugar companies around the world follow protocols determined by ICUMSA, the International Commission for Uniform Methods. The ICUMSA standards define color values for the sugar, stated in terms of international units (IU). An average white sugar has a value of 30-35 IU; a very pure, low-color sugar falls in the range of 15-20 IU; darker 'raw' sugar might have a value as high as 600 or even 1000 IU. The test protocol most often implemented at American Crystal Sugar is known as ICUMSA-420. The '420' refers to the specific wavelength of light used during analysis, 420 nm. Several other ICUMSA methods exist, designed for specific needs such as analysis of colored syrups or to determine the turbidity of a sugar solution. However, the most commonly used test at sugar producers like American Crystal Sugar is ICUMSA-420.

Producers assign each batch of sugar a specific color value. That value is determined by the amount of light absorbed by test samples when those samples are inserted into a spectrophotometer. An aqueous solution of pure sugar does not absorb 420 nm light, while major contaminants such as molasses absorb strongly at that wavelength. Thus, lower absorbance leads to lower IU values, which equate to purer sugar.

During processing, analysts need to know in real time whether the conditions for the current batch of sugar require adjustment. "Adjustment" could mean adding more water to the batch, increasing carbonation levels, or extending its spin time in the centrifuge. In rare occasions, an upset in the sugar process might cause a rise in color value to such an extent that the product would be unsellable. The ability to determine that color value before a batch moves too far through the refinement process can avert the need for a total remelt and recrystallisation of the product. To remelt a batch of sugar takes several hours and imparts significant expense to the producer.

The color value of a batch of sugar is important to customers. "There are different customers that will ask for colors that are different," Bailey explained. One particular soft drink company "does a throwback [formula] where they use sugar instead of corn syrup." The company is very particular about the color of their final product. They require it to be a particular and widely recognized shade of yellow. The sugar cannot darken the final product, Bailey said, "so they ask for a lower color sugar than some other people would." Other customers such as chocolate makers are less concerned if the sugar they buy is darker because their additional ingredients (e.g., cocoa powder) will mask the sugar color. Bailey pointed out, "If we were to send a sugar that didn't fit their specs properly… that could be a big complaint for us from a customer." Therefore, the primary concern is that the reported color value is accurate.

A solution

American Crystal Sugar Company determined that the Thermo Scientific™ GENESYS™ line of visible and UV-vis spectrophotometers was ideal for its needs. The instruments are compact and sturdy enough that it was feasible to acquire several of the devices and positioning them in multiple locations along the production lines throughout each plant. Because the GENESYS UV-Vis Spectrophotometers can read the entire ultraviolet-visible spectrum, they are able to be used for other quality assurance tests if need be. This versatility is just one more reason why sugar production companies tend to use a spectrophotometer instead of a more limited device like a colorimeter.

Advantages and applications

American Crystal Sugar uses exclusively GENESYS Visible and UV-Vis Spectrophotometers at all five of their sugar processing plants. The instruments demonstrate consistent accuracy across a wide range of concentrations, delivering trustworthy results whether a sample's color value was high or low. This dependability is important, because ICUMSA tests mandate quantifiable values. Customers expect quantified values too.

The ease of operation of the GENESYS 140 Visible Spectrophotometer provides another advantage to a large company like American Crystal Sugar. It is a "plug-and-play" instrument; the user inserts in a water blank for calibration, then removes the blank and inserts the sample. From this point forward in the analysis, the spectrophotometer effectively runs itself. Training workers how to use the instrument is very straightforward. Teaching workers how to perform proper sampling and testing procedures takes more time than generating the results for those samples.

The capability of GENESYS 140 Spectrophotometer to be programmed simplifies operation further. The IT staff at American Crystal were able to write a custom program in-house for the spectrophotometer that automatically registers the sample's absorbance, processes the data, and reports back a color value in IUs. Such custom programming shortens time from sampling to actionable test result. The quick turnaround time enables workers to address any immediate production issues revealed by the tests.

An aspect of GENESYS Spectrophotometers that Bailey finds most impressive is their ability to repeatedly deliver reproducible results from one instrument to the next. To ensure all the chemists across their plants are performing consistent analyses, American Crystal Sugar holds a monthly meeting to standardize their testing methods. All procedures are uniform for the entire company, and equipment is identical across five factories. The chemists will run company-wide assays on a known batch of sugar, with individual analysts performing the same tests on different spectrophotometers. The assurance of consistency that results from different people testing the same known batch of sugar across multiple instruments at all five locations, and then delivering statistically similar results, reinforces confidence in the company's products, their methods, their people, and the spectrophotometers. "If there were a significant difference in the results then we would have to look at that and say, is there something going on with the machine? Is there something going on with the analyst?" Bailey said. Any significant difference in results would need to be investigated to determine why the discrepancy arose. "Honestly," Bailey admitted, "month to month as those [test results] come back, those numbers are all very close." This is how he knows that Thermo Fisher Scientific's spectrophotometers are generating dependable results, so American Crystal Sugar can have confidence in the sugar they send out.

Conclusion

The nuances of sugar color can mean the difference between a happy or dissatisfied customer, or the decision to completely reprocess of a batch of sugar. The GENESYS 140 Visible Spectrophotometers and GENESYS 150 UV-Vis Spectrophotometers used by the analysts at American Crystal Sugar are essential tools to monitor the color value of their products. They know they can trust the instruments, the analytical process, and the final sugar. If a flawed quality analysis resulted in a color issue, the company might have to recall that load—and that would be hugely expensive. To date, the machines have worked so well that they have not encountered such a problem. For the needs of one of the largest sugar beet producers in the U.S., American Crystal Sugar Company, GENESYS Visible and UV-Vis Spectrophotometers really are a sweet solution.

GENESYS 150 UV-Vis Spectrophotometer

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