I am a process engineer at American Crystal Sugar Company in Crookston, Minnesota. Last year we did a one-month trial with the FBRM.
In this presentation, I will introduce you to the sugar-refining industry and go through some process flow diagrams to show where there is potential application of the FBRM instrument. We compared the results we got during the one-month trial with FBRM to what was going on according to factory operating numbers. I will present some conclusions based on FBRM data that was then turned over to management for a decision to purchase an FBRM.
American Crystal Sugar Company refines sugar from sugar beets. Our corporate office is in Moorhead, Minnesota. We have five factories along the Red River between North Dakota and Minnesota where we process between 8 and 10 million tons of sugar beets per year. We are a farmer-owned cooperative. Our beets are grown on 2400 different farms. With roughly 2300 employees, we produce 2 to 2.5 billion pounds of sugar every campaign, for total sales of around $600 million.
This is a flow diagram of our process. We bring in sliced beets and enter those into a counter-current extractor where water is added. The water leaches out the sugar, as well as mud and other impurities that are in the beet. The sugar water then goes on to a purification and clarification step where we add calcium hydroxide followed by carbon dioxide to precipitate out calcium carbonate. This is done in a thickener. The mud that falls out of the thickener goes on to waste storage.

The purified juice, which has lost about 30% of its impurities, goes on to a multiple-step evaporator station where we increase the concentration from roughly 17% solids going in to 75% coming out. The stream leaving the evaporator station is then sent to crystallization where we have a three-step crystallization process.

The crystallization process starts with the white pans, where white sugar is made. It goes on to the intermediate step, where a medium-grade sugar is made, followed by the raw pans, where low-grade sugar is made. All of the sugar that is produced in the bottom two stages (in the intermediate and raw pans) is then re-melted and sent back up to the white pans to try to get out the white sugar.

In our particular factory we slice roughly 6000 tons of beets per day. From there we make about 17,000 to 18,000 hundredweight of sugar per day. Crystallization is a very critical step in the factory operation and needed some attention.
Introduction

• Is sugar boiling an art??????
• Solubility, saturation, and supersaturation coefficients are hard to measure and understand.
• Need for simplification.
• What about size?
• MA/CV are after the fact.
• Can size be measured on-line?

Everybody who has been in the industry at least 30 years says that sugar boiling is an art. It takes a special type of person to do it. But I felt there was a need for a simplification method. Maybe there was something out there that could be used on line to help us understand this process a little better?

Solubility, saturation, and supersaturation were our main concerns. We process 6000 tons of beets per day and harvest between 8 and 10 million tons per year. The harvest period takes place during the first two weeks in October, and then the beets are stored throughout a 250-day campaign. They are placed in piles 20 feet high and 800 feet long for an extended period of time. The beets respire, so there are a lot of different chemicals that become part of the impurities in the process and ultimately end up in the crystallization step. Things are changing all of the time, so it’s hard to get an on-line measure of how we are doing on our saturation curves.

We have a specification in each of the factories where we have to boil sugar to a certain size. MA is mean average and CV is coefficient of variants. This is basically an after-the-fact measurement where they take dry sugar, run it through a bunch of different pans, get a certain mass on a pan, and put it in this formula that gives the MA. Our MA at Crookston is 14.5 to 15.5. That equates to a particle size of roughly 370 µm to 450 µm. As I said earlier, this is done after the fact. After the product is run through the dryer and through the scrolls, then the measurement is taken.
I was fortunate enough to go to a crystallization seminar put on by the American Institute of Chemical Engineers. There, I found that there were quite a few people interested in crystal size. People working with surfactants, in chemical purification, and in the pharmaceuticals industry all had concerns similar to ours.

Everyone agreed that crystallization was a good way to purify a product and I had a chance to talk to several people about this. They asked if I had ever heard of a Lasentec particle-size analyzer. I had not, so I got in touch with Lasentec and we were set up for a one-month trial at our factory.
It seemed FBRM would be a good technique for us. The instrument shoots out a laser beam that comes back, giving a chord length measurement that is proportional to the rotational speed of the lens. It made sense to me that this would be a simple way for us to look at things. But, as I hadn't seen anything in the literature related to the use of this technology in sugar refining, we weren't sure it would work.
We put the FBRM into one of our white pans for a one-month trial. The installation was relatively easy; all we needed was a one-inch coupler and a compression fitting. We tried to set the probe into the pan at a 45-degree angle. This particular pan was a 1600ft³ vessel. It is a semi-batch operation where first liquor is fed continuously throughout a 2-1/2 hour period. It operates under a vacuum and has an absolute pressure between 3 and 5 pounds. We boil at roughly 75°C to 85°C.
I was pleased to find that the equipment associated with the FBRM probe did not take up very much space. We set up the control module (or field unit) and the mixer for doing the calibration. We had a spare computer lying around the factory onto which we installed the FBRM software.

I really liked the fact that we could monitor the pan on line. If there was a particular point within the crystallization process where we wanted to go back and compare to the previous pan, the software enabled us to put both versions up on the screen and compare the counts. FBRM was very versatile and I enjoyed using it.
With the FBRM, we gathered data into four different size ranges: 1 to 50 µm, 50 to 100 µm, 100 to 250 µm, and 250 to 1000 µm. Based on what we were getting in the lab, I didn’t expect much in the bigger size range, but we found FBRM to be very sensitive to the small ranges. We could see the 0-to-50µm particles quite readily.

When I first saw this data, one thing that stood out was an increase and then decrease in small particles. During normal operation I would expect these particles to keep growing. So I went and talked to the people who were operating the vessels and asked what they were doing that was getting rid of the smaller particles. They told me the small particles were probably picks, particles formed during nucleation when supersaturation gets too high. They thought the pan was probably picking, so water was added to the vessel to get them out. I asked if this happened very often and they said yes, especially now.

At the time we were running this trial (last March) we were having a lot of production problems. The sugar wasn’t spinning out in the centrifugals very efficiently, so we had a lot of spin time on the centrifugals. We also had a lot of wash water to wash the color out of the high-color solutions and it wasn’t drying very well.
I went back and looked at a few more pans and saw the same behavior. In this graph, the red line is the small particles and the blue line is the valve position. With FBRM, I was able to track the valve position along with particle size and was able to show that at each instance we could get the small particles to disappear by opening the valve.

This wasn’t good. We had spent a lot of money to evaporate the solution to concentrate it up to 75 brix (what the sugar industry calls percent solids) and now we were adding water in the final crystallization step. It didn’t make sense, but it was a very common practice in our factory.
With this in mind, I went back and looked at a one-month time period when we were having a lot of trouble with our sugar processing. I looked at some of the other problems our operations people pointed out (e.g., feed liquor rates that were coming in too high) and trended the information to see if we could control the first-liquor brix.

This is a plot of first-liquor brix. We try to shoot for 75 brix coming out of the evaporator station, but there are periods when we got up to 78 brix and stayed there for quite awhile. The red lines are the water valves on the pans. We were adding a lot of water to dissolve these little crystals. After we plotted this and discovered what we were doing wrong, we went back and set a factory target of 75 first-liquor brix. This was in the middle of March, so we had been running the FBRM for roughly two weeks.
Our year-to-date average in the factory up to that point was 17,500 bags of sugar per day. From March 15, there were 60 days of campaign left and for 20 of those 60 days we had record sugar production in excess of 20,000 bags of sugar per day, simply because we were able to fine tune the first-liquor brix so the crystallization step would be optimized.

This graph shows a broad range of first-liquor brix. I went back and averaged our sugar production based on these numbers and found that at the lower concentrations, we did have a higher throughput in the factory. But some of the factory personnel thought that we might have just had a higher purity of sugar during those times. The purity of the solution changes throughout the campaign and they thought maybe we had run into better purities of solution, which allowed us to crystallize better. So I told them I would redo the averages with purity.
All of the records after March 15 had a first-liquor brix of 75 and a purity of 93.5. When we plotted the purity, we saw that 93.5 was right in the middle. If purity alone were the most influential factor, we would expect that all of our big days in the sugar factory would have been at the higher end. But it turned out that at the record days we were in the 93.5 range. We concluded from this that first-liquor brix did affect the crystallization and enhance the throughput of the factory.
Conclusions and Recommendations

- The Lasentec FBRM is very easy to install and operate.
- The Lasentec is able to quantify the number of small particles “picks” within the white pan boiling process.
- FBRM can be used as an pan boiling optimization tool.
- Could potentially by used in other parts of the factory, namely, purification where particle size and settling is important.
- Could be set up as a mobile unit, factory to factory.
- American Crystal Sugar should purchase a Lasentec FBRM to be used among the 5 factories.

We found that the Lasentec FBRM was very easy to install and very factory-friendly. We were able to track the picks within the process and find out when they were coming in. We were able to change the way we ran the factory based on the information the FBRM was giving us and can use FBRM as an optimization tool to find out where we should be (at what brix) at what part of the campaign.

FBRM could potentially be used in other portions of the factory as well. There is a purification step and a clarifier where we use different flocculants to make calcium carbonate precipitate out more efficiently. Because we have five factories, one suggestion was to get a mobile FBRM that could be moved from factory to factory. Each factory has about 15 different crystallization vessels that operate under the same conditions.

We submitted a rate-of-return capital project to purchase an FBRM. It was accepted and we got our instrument a month ago. The factories that have heard about this have already requested to use the FBRM. They are having crystal separation and drying problems, so we think it will be a very well used tool.
Q: Was there a port in the side of your pan already or did you have to poke a hole in it?

JS: Before our campaign even started, I knew we would probably be trying FBRM, so we had a port installed in one pan. We have three pans that do the white crystallization, so we have some redundancy. We were able to take one pan off line during the campaign and install the port. It was an easy installation that only took a half hour.

Q: Did you have trouble convincing anyone to poke a hole in the side of the pan?

JS: We had results from the trial and knew FBRM would work. The operators were beginning to realize that it was easier to understand particle size than supersaturation. Once we showed them a plot and gave them a number to shoot for, they jumped on the bandwagon relatively easily.
Q: How were you identifying your picks before you had FBRM?

JS: Each pan has a window so you can look at the level. There is scope on the pan, a visible light, where you can see crystals flying by. That’s how it was quantified.

Q: What do you mean by brix?

JS: Brix is what the sugar industry calls percents solids.

Q: So it is a concentration measure?

JS: It’s RDS, so it’s refractive.
Q: The real utility you’ve demonstrated with your plots was the ability to look at each vessel on line and determine what to do with it. How do you plan on sharing one instrument between five plants and still get the good results you want to have?

JS: That’s the big question. At Crookston, we have eight crystallization vessels. We have one instrument and five ports. And we’re the smallest factory in the company. The other factories have as many as 15 or 20 vessels. I’m guessing that once we get the FBRM going around to the other factories, they’re going to want one of their own.

For me, the big benefit was proving that there was something out there that could track sugar crystallization well and could tell us that the small crystals were the ones that were causing us problems. My justification is already done. The savings we registered during the record dates last March already warranted the purchase of the FBRM.
Q: You mentioned you use a seeded batch of raw sugar. So you seed the crystallizers?

JS: Yes, we do seed the crystallizers. The pans are seeded at 200 to 500 ml of what they call “moose milk.” Moose milk is sugar that’s been put into a rotary mill. We put isopropyl alcohol in and rotate it for 24 hours and then get this volume of moose milk.

Q: So you don’t actually control the particle sizes but you have an empirical method for making the seeds?

JS: They have a recipe for doing it. That’s another application of FBRM – monitoring how consistent are we on moose milk generation. The more we get the FBRM into the factories and see what we are doing in relation to particle size, the more they will see its versatility and value.
Q: But if you already know that the problem was your first-liquor brix needing to be at 75, why would you need to figure that out again at each factory?

JS: That 75 is for one portion of the campaign. At the end of the campaign, when we have different impurities, it may be 74.5 or something like that. The bad thing about our industry is that we have to store the beets for a period of time and we have to keep optimizing where our boiling curve is. FBRM will be a big tool to help do this. Also, we were being conservative. Maybe we could have gone to 76 and gained more efficiency in our evaporator station. That is something to try in the future. It is more cost-effective to evaporate in the evaporator station than in the white pan.