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Pages 340-343

SUGAR PROCESSING AND REFINING  >  POWER AND COGENERATION  >  BIORENEWABLES  >  AGRICULTURAL PRODUCTION
MARK YOUR CALENDAR!

The 29th International Sweetener Symposium will be held August 3-8, 2012, at the spectacular Coeur d'Alene Resort in Coeur d'Alene, Idaho. Attendance at this year’s Symposium is a must for all industry stakeholders given the critical state of play of sugar policy with the pending renewal of the Farm Bill. Will we have a completed Farm Bill by August or will it still be a work-in-progress? Additional program topics will include the U.S. and world market supply-demand outlook, the effect of multilateral, regional and bilateral trade agreements on world sugar policies and U.S. commodity programs, trends and forecasts in the food sector, the upcoming Congressional and Presidential election outlook and other key topics. All industry players will want to explore these issues with the Symposium’s panels of renowned industry experts and key policymakers. Listen, learn, and add your views at lively and informative sessions on these and other vital topics.

Traditionally around 400 people from all sectors of the sugar, corn sweetener and food manufacturing industry attend the Symposium to hear the most significant and timely issues affecting the industry and to network with their sweetener industry colleagues. In addition to the compelling program content, the Symposium schedule allows free time every afternoon to enhance your industry relations in this comfortable setting.

This year’s location is the Coeur d’Alene Resort. Located in scenic northern Idaho on the western edge of the Idaho Panhandle, this charming town sits just 31 miles east of Spokane, Washington and 100 miles south of the Canadian border. This world class resort is ideally located on the shores of spectacular Lake Coeur d’Alene in the foothills of the Bitterroot Mountains. Coeur d’Alene Resort features luxurious accommodations, distinctive dining, a full European spa, an outdoor infinity edge swimming pool, a private beach, a children’s program, retail shops, several restaurants and hiking right next door at Tubbs Nature Preserve. But the resort’s crown jewel is its extraordinary golf course which consistently ranks in Golf Digest’s “Top 25 Resort Courses in America” and is home to the world’s only floating movable green.

Known as the “lakeside playground,” Coeur d’Alene offers a bounty of water activities including the world’s longest floating boardwalk, a marina, boating, fishing, jet skiing, parasailing, lake cruises, kayaking, stand-up paddleboarding, and more. And to further complement the resort, the thriving town of Coeur d’Alene is located just steps from the resort and offers over 100 shops, boutiques, restaurants, microbrews, festivals, Fort Sherman Park, and biking. This world class location offers something for everyone. For a pre- or post-Symposium stay, consider a trip to Glacier National Park (4 hours drive), Washington State’s wine country (3 hours) or Banff, Canada (7 hours).

This is one sweetener industry meeting you won’t want to miss. Preliminary program and registration materials will be available in May. For more info on the Symposium, visit www.sugaralliance.org/symposium.
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  - production of glucose and fructose syrups from starch
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- Co-refining: integrating cane sugar in beet sugar factory
- Co-product valorization: bioethanol vinasses, glycerol, betaine

Contact: industrialbiotech@novasep.com
International Sugar Journal

309 Phenolics in sugar cane juice: Potential degradation by hydrogen peroxide and Fenton's reagent
D.M.T. Nguyen and W.O.S. Doherty

316 Experience with continuous crystallization of refined sugar at United Sugar Jeddah
A.S. Vawda, A.E. Muneef and M. Voelling

324 Agricultural use of filter cake from the Tongaat Hulett sugar refinery
P. Allen and N. Padayachee

328 Sugar house training simulator
R. Mazaeda, A. Merino, C. de Prada and L.F. Acebes

344 Identification of three armyworm species (Lepidoptera: Noctuidae) using DNA barcodes and restriction enzyme digestion
N. Joomun, S. Ganeshan and A. Dookun-Saumtally

350 Identification of intergeneric hybrids between *Erianthus arundinaceus* and *Saccharum spontaneum* through STMS markers
P. Govindara, A. Balamurugan and U.S. Natarajan

359 Biosecurity against invasive alien insect pests: A case study of *Chilo sacchariphagus* (Lepidoptera: Crambidae) in the southern African region
M.J. Way, D.E. Conlong and R.S. Rutherford

Product Features

335 Reducing colour helps reducing sugar loss in refinery: Process problems and adapted solutions
E.M. Sarir, C.A. Donado, R. Villanueva, A. Boghari, H. Tobar, A. Solatorio and E. Espanueva

340 BMA - Batch centrifugals: Have we come to the end of development?
S. Stiegert, I. Geyer, D. Spangenberg and A. Lehnerger
PhD, Former Director of Research at Monitor (now Michigan) Sugar Company, USA.
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Editorial Comment

Can Brazilian sugar industry deliver the expansion in future demand?

In their report over a year ago, Czarnikow noted that by 2030, global sugar demand will increase to 257 million tonnes raw value from current 168 million tonnes. This is a conservative forecast as it does not include increasing demand for sugar for industrial use, particularly in the production of both biofuels and biochemicals. Nonetheless, to meet this rising demand, the report was emphatic, “world dependence on Brazil to supply sugar will continue to grow”. It has suitable agricultural land in which to expand cane production. “For Brazil, expansion prospects are significantly better than others worldwide” the report noted.

However, the credit crunch of 2008 exposed both weaknesses and poor decision making that continues to beset the Brazilian sugar industry, exacerbated by rise in production costs. Many mills are paying the price for over expansion during 2006-2009. Investment in agricultural production was somehow neglected. Ratooning was extended as the replanting costs of 4800-5300 Real’s ($2580 - $2849) were high. As a result, with more cane production coming from low yielding aging ratoon crops, cane yields dropped from 89 t/ha to 69 t/ha.

According to UNICA, over the last five years, field production costs have increased by 38.5%, mainly in land leasing (+57.12%), as well as in manpower (+47.12%) and mechanisation (+28.17%).

While some of the leading millers have invested significantly in agriculture to address the under-performance, for more than a few mills, staying competitive has become a serious issue. According to an industry consultant Ricardo Pinto, currently there are some 39 mills in most of the cane growing states going through bankruptcy (Table 1). An informed source at Bunge suggested that banks are probably considering more than this number.

Table 1. Sugar/ethanol plants in Brazil going through Recuperação Judicial (judicial reorganisation)

<table>
<thead>
<tr>
<th>State</th>
<th>Number of factories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alagoas</td>
<td>3</td>
</tr>
<tr>
<td>Bahia</td>
<td>1</td>
</tr>
<tr>
<td>Espirito Santo</td>
<td>2</td>
</tr>
<tr>
<td>Goiás</td>
<td>1</td>
</tr>
<tr>
<td>Minas Gerais</td>
<td>4</td>
</tr>
<tr>
<td>Mato Grosso do Sul</td>
<td>3</td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>3</td>
</tr>
<tr>
<td>Pernambuco</td>
<td>4</td>
</tr>
<tr>
<td>Parana</td>
<td>1</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>2</td>
</tr>
<tr>
<td>Sergipe</td>
<td>1</td>
</tr>
<tr>
<td>Sao Paulo</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
</tr>
</tbody>
</table>

Source: Ricardo Pinto (pers. communication)

Table 2. Impact of EU sugar reform on production and productivity

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Before reform 2004 - 2006</th>
<th>After reform 2008 - 2010</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>White sugar yield (t/ha)</td>
<td>8.7</td>
<td>11.0</td>
<td>26.6</td>
<td></td>
</tr>
<tr>
<td>Campaign length (days)</td>
<td>91.1</td>
<td>110.8</td>
<td>21.6</td>
<td></td>
</tr>
<tr>
<td>Sugar production per factory (’000 t)</td>
<td>122</td>
<td>170</td>
<td>39.2</td>
<td></td>
</tr>
<tr>
<td>Productivity per labour unit (t sugar/employee)</td>
<td>387</td>
<td>553</td>
<td>42.9</td>
<td></td>
</tr>
</tbody>
</table>

Source: Agrosynergie, Dec 2011

Over the last decade, sugar production costs have practically quadrupled. The relative cost advantage the industry once had eroding fast. Combination of high inflation (around 6% compound through to 2016 according to IMF), high cost of borrowing (6% in real terms, though the domestic cost is 12%), and increase in the cost of hard commodities, particularly steel, has added to its competitive woes.

While the government has woken up to the stagnation in the sector through actively promoting replanting of 1 million hectares via Banco Nacional de Desenvolvimento Economico e Social, Brazil’s national development bank, which will loan mills 4 billion reais for this purpose, one cannot help noticing this as reactive move. Indeed the policy making in Brazil for this sector has largely been reactive.

There is little doubt that Brazil will continue to be a major force in the global sugar industry. But there is an increasing doubt as to whether it will be able to lead the expansion in sugar in the manner that many analysts predicted. There is a compelling case for more government supported proactive policy, rather than mainly relying on market forces. Whatever one may think of the heavily regulated EU sugar sector, the reforms it instituted several years ago has significantly and positively impacted the performance metrics (Table 2) and the growing competitiveness of the industry in the global scene. Perhaps Brazil should take a lesson from this. •

Arvind Chudasama
Brazilian cane growers to replant some 1.5 million hectares to boost productivity

With the aim of restoring cane productivity which has seen significant decline recently due to extended ratooning, cane growers in Brazil are said to spend as much as 6 billion reais ($3.4 billion) this year to replant cane, Bloomberg reports.

Some 1.5 million hectares (3.7 million acres) or 15 percent of cane fields is likely to be replanted with this investment according to, Antonio de Padua Rodrigues, technical director for the sugar-cane trade group Unica. Last year the nation renewed 1 million hectares.

Brazil is seeking to boost cane production after a shortage of ethanol drove up prices last year and prompted the government to reduce the blend rate into gasoline. Mills will probably operate at 80 percent of capacity this year after cutting investments in new fields, which typically are renewed every five years to maintain yields. “This quantity of renewals needs to happen each year,” to guarantee ethanol supplies, Rodrigues said.

Cane-growers are currently using their own funds and will probably begin to access a special government credit line offered to promote replanting. Yields will increase this year because mills replanted 40% more cane in 2011 than the previous year. Companies are expected to replant 20% more cane between January and April from the same period last year, Rodrigues said.

If current investment trends continue, it is anticipated that the nation’s mills will be functioning at full capacity by 2015. In the recent past, cane yields have dropped from 80 t to 69 t/ha due to extended ratooning.

Banco Nacional de Desenvolvimento Economico e Social, Brazil’s national development bank, will loan mills 4 billion reais to replant 1 million hectares and develop new ones, the lender said.

“Most of this line will be utilized,” Rodrigues said.

“Many big groups are preparing documentation and procuring environmental licenses” to start tapping the credit.

India - Sugar output likely to drop in 2012/13 due to dry weather

Sugar output from the 2012-13 crop in India is likely drop for the first time in four years next season as dry weather in some regions spurs farmers to plant other crops, reports Bloomberg, citing Charlotte Kingsman, a New Delhi-based sugar analyst.

The harvest may total 24.5 million metric tons in the season beginning 1 October compared with 26 million tons this year. Sugar exports are likely to continue for a third year as supplies from the new crop and inventories will exceed domestic demand by about 6.5 million tons. On 26 March 2012, Indian government allowed exports of a further one million tonnes of the commodity. This takes the total exports allowed for the year at three million tonnes for the 2011-12 marketing year.

“Whether the government allows some more exports on top of the 3 million tons already announced will depend on domestic prices and cane arrears,” Kingsman said. “In theory, India has the capacity to export more than 500,000 per month, so the sugar could move out without too many difficulties.”

Sugar mills are seeking approval for additional exports as they need money to pay farmers for cane. Sugar-makers owed growers 84 billion rupees ($1.6 billion) in arrears as of Feb. 29, Food Minister K.V. Thomas told parliament on March 26.

Indian government has recently relaxed rules for exports which removed the quota on individual mills to export sugar and has now permitted exports on an open-general-license basis. While exports will be possible from mills located near the coast, sugar prices across the country go up as supply within the country reduces.

“Farmers seem confident that they will receive the amount due,” Kingsman said. “We do expect a drop in acreage in Maharashtra. The drought in certain areas has pushed some farmers to switch to less water-consuming crops like soybean, even though the returns are not that good.”

What has not been kept in mind, however, according to Business Standard (India), has been that the policy has led to a sharp reduction in sugar inventory in the country. India, as per a report in Futures Magazine, has been maintaining an inventory level of about 50% of consumption. This, after accounting for the current set of exports will bring down the stocks to 27% of usage.

Sugar prices in the commodity exchanges have moved up from a low of Rs 2718 (U$53) per quintal (100 kg) to the current level of Rs 3076 (U$60) per quintal.
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Nigeria - Government approves plan to expand sugar production

Nigeria’s government said it has concluded work on a National Sugar Master Plan (NSMP) that would save $416 mn (NGN68.6 bn) in foreign exchange and generate over 100,000 jobs from local production of sugar, scheduled to commence by 2015.

Currently, Nigeria produces only about 2% of its domestic consumption from local feedstocks.

The NSMP targets for sugar output of 1.797 mln tonnes, 161.2 mln litres of ethanol, 4,000 MW of co-generation capacity, 1.6 mln tonnes of animal feeds as well as 37,378 permanent jobs and 79,803 seasonal jobs, the Minister of Trade and Investment revealed.

Brazil - Improved port facilities and dry winter expected to foster smooth flow of sugar exports in 2012

Bottlenecks at the key sugar port Santos which stifled smooth flow of sugar exports two years ago is unlikely to be repeated this year. Long-range weather forecasts indicate a dry winter, meaning there is unlikely to be a repeat of the disruption two seasons ago. Further, the opening of an additional bulk-loading terminal at Santos and the deepening of canals there and at Paranagua are additional assurance that long and costly delays for loading are improbable, reports Reuters.

Torrential rain in 2010 slowed sugar loading in Brazil, forcing more than 120 ships to wait for weeks to pick up their cargo at Santos and Paranagua. Even small amounts of rain falling into ships’ holds can damage sugar loads, making it hard and lumpy.

“We expect it should be quite fine in terms of sugar loading. Our expectation is that things will be similar to last season,” said Nicolle de Castro, commercial assistant at Santos-based SA Commodities/Unimar brokergae and shipping agent. Loading disruption in 2010 coincided with a spike in sugar demand when supplies from some Asian sources faltered. This resulted in New York sugar futures to jump to around 28 cents/lb between the start and peak of harvesting. Costs for shippers also headed skyward when rain held up loading in 2010. Demurrage charges alone are typically around $15,000- $30,000 a day.

In 2010 the El Nino weather anomaly, which turns southern Brazil wetter than normal, halted round-the-clock sugar loading for days. Its opposite, La Nina, brought dryness this year but the anomaly is fading. Though forecasters say an El Nino could recur, its effects will not be seen until after harvest’s peak. “In autumn, by the end of March we should already have neutral (El Nino/ La Nina) conditions, which should be observed through autumn and through the winter also,” said Olivia Nunes, meteorologist at Sao Paulo-based Somar Meteorologia. “It won’t be a wet winter but it will be one with normal levels of rain,” she said.

Somer’s forecasting models made no prediction of another El Nino but US-based World Weather Inc said it expected the anomaly to kick in later in the year. It cautioned forecasters were still not in unison on the likelihood it would occur. Reinforcing capacity, Asia’s biggest commodities trader, Noble Group, inaugurated a sugar-loading terminal in Santos in October last year, adding nearly 11 million tonnes a year of bulk capacity to that port.

Brazil exported about 26.5 million tonnes of sugar, raw and refined, in 2011, trade ministry data shows. The new terminal adds welcome extra capacity as Brazil pursues rapid expansion of cane production, Rumo Logistica, the logistics arm of major Brazilian sugar producer Cosan, has announced plans to install a rigid canopy stretching over the berth to cover ships’ holds and enable all-weather loading but works have still to commence.

The destruction of two huge rocks in the access canal to Santos and the removal of a freighter that sank decades ago will also enable larger vessels to dock once dredging has been carried out at the berths, de Castro said.
South Korea - Government takes the initiative of importing sugar

The first shipment of sugar imported directly by the government will arrive in Korea next week that could help stabilize the commodity’s price here, according to a state corporation. The Korea Agro-Fisheries & Food Trade Corp. said 2,000 tons of sugar imports will arrive at the southeastern port of Busan on 19th March to be sold at low prices to processed food manufacturers such as confectionery companies and bakeries reports Yonhap News.

The shipment is part of the 10,000 tons of sugar the government bought from Thailand and other Southeast Asian countries last month.

The move aims to break up the oligopoly on sugar imports that have been handled by three companies in the past. This tight control has been cited for high domestic sugar prices that adversely affect the government’s efforts to check inflationary pressure.

“International sugar prices have stabilized in recent months, but this has not been reflected in the domestic market due to a few companies controlling all imports,” a spokesperson for the trade corporation said. He said by directly importing sugar, Seoul is moving to diversify the local distribution network and help processed food manufacturers.

Lowering sugar prices is important because it makes up 10-15% of the cost for beverages. It also accounts for 8-10% of cookies and pastries and 3-5% of the cost for bread and ice cream.

Last year, Seoul announced it would levy no duties on 300,000 tons of sugar to get more private companies to bring in the food product, but the plan made little headway because of the inflexibility of the local distribution network and clout exercised by the established importers.

New cane sugar production project underway in Ethiopia

A sugar development project is in progress in Tigray Regional State, Ethiopia according to Abaye Tsehaye, Director General of the Ethiopian Sugar Corporation, reports the Ethiopian News Agency. More than 40,000 hectares of land has been allocated for sugarcane production, with 10,000 earmarked for the construction of a sugar factory with quarters for employees explained Abaye. Cane will be irrigated. Water will be sourced from an irrigation dam that will be built near the site.

The project is expected to create employment for 10,000 people.

Details of cost, factory capacity and major investors were not revealed.
Sugar lobby compliments US sugar policy

American Sugar Alliance (ASA), the sugar lobby group for the combined beet sugar, cane sugar and HFCS sectors, recently complimented the no-cost sugar policy passed by Congress in 2008, via a written testimony to the Senate Agriculture Committee.

“US sugar policy has been a resounding success during the 2008 Farm Bill and deserves to be extended,” ASA wrote. “It has achieved its goals of providing reliable supplies of high-quality sugar at reasonable prices, and a critical safety net for producers. It has done so without government expenditure. Furthermore, if extended, USDA predicts zero expenditure through 2022.”

Over the past 19 years, there has considerable rationalization in the industry with widespread closures of sugar facilities and loss of 139,000 jobs on the back of low, stagnant prices and rising input costs. But there have been fewer facility closures under the current Farm Bill than any of its predecessors.

American consumers are also the beneficiaries of Bill, states ASA, as they claim that global surveys indicate that, “consumer prices in the rest of the developed world have averaged 10 to 30% higher than here.”

Another group of beneficiaries are confectioners - who, despite opposing the sugar policy - have increased US production by 2.5% since the 2008 Farm Bill became law, according to US Census data. “There are press releases and news reports virtually every week about strong profit statements and expanding operations in the food manufacturing sector,” ASA testified.

Foreign sugar producers are also thriving under the current policy, which is why many overseas producers are joining their U.S. counterparts in urging Congress for an extension.

“Our are more open to foreign sugar than any other major sugar producer and are the world’s largest sugar importing country,” explained ASA, “In recent years, we have imported an average of 30% of our needs.”

Mitr Phol to build $1.58 bln sugar factory in China

China’s government has partnered with Thailand’s Mitr Phol Group to establish a new sugar mill in the city of Chongzuo in the top cane-producing province of Guangxi, according to China Daily newspaper.

The plant is expected to be the largest sugar mill in the country upon completion but a timeline was not provided. Total investment of the facility is expected to be CNY10 bln ($1.58 bln). The first phase of the project is expected to cover 18 square km, said Jiang Liansheng, deputy secretary of the Chongzuo City Committee of the Communist Party of China.

Details on production capacity of the factory, when it will come online, how many growers will supply cane or how many hectares are devoted to the supply cane have yet to be disclosed.

EnerDry bags a deal to supply beet pulp steamdryer in Serbia

EnerDry ApS recently sold a steamdryer for the beet sugar factory Pecinci belonging to Sunoko d.o.o. in Serbia. The construction of the unit has commenced. It shall be operational before the campaign starts in 2013. Installation of a steamdryer unit is also planned for another factory belonging to Sunoko. The technical director Dusan Stojanovic and his team have examined the market for pulp dryers and concluded that a steamdryer from EnerDry is the right decision. They have found that EnerDry is the leading player in the beet pulp drying in steam under pressure. Its proven technology is ideally suited for their needs, with the added bonus that its steamdryer is cost effective in terms of energy use and environment-friendly by minimizing air pollution.

“We are pleased to have secured Sunoko’s as our customer” said Arne Sloth Jensen, CEO of EnerDry.

“We fully expect to demonstrate the high efficiency and commercial viability of our steamdryer.”

EnerDry’s steamdryer effectively dries beet pulp with steam supplied under pressure. Compared with drum drying, the steamdryer results in a saving of at least 95% energy use, as the water that was in the pulp is returned to the juice evaporation as full useable 3.5 bar steam. Consequently, air pollution, apparent with the alternative beet pulp drying technology, i.e. drum drying, is fully avoided.

It is claimed that the return on investment from the installation of EnerDry’s steamdryer is secured over a short period.

All leading beet sugar companies in USA and Japan have EnerDry’s steamdryers and many steamdryers in Europe are based on the EnerDry patented technology.

Sudan - Official launch of White Nile Sugar Project postponed

The inauguration of the over $1 billion White Nile Sugar Project (WNSP) in Sudan on 5th April was called off at the last minute due to the impact of US sanctions which blocked the delivery of computer software needed to run the factory.

Apparantly the company originally contracted to supply the software was taken over by a US based company which refused to honour the contract in compliance with the decades-long sanctions imposed by Washington.

Informed sources connected with the WNSP suggest that this is a minor setback as an alternative supplier has been sought and the required software will soon be in place.

When the sugar factory comes fully online by 2014, the 450,000 tonne sugar factory, arguably the biggest in the cane sugar sector with capacity to process 24 t cane/day, will help achieve self-sufficiency in sugar in Sudan.
Construction of the Sh16 billion (US$192 million) Kwale integrated sugar mill near Mombasa in Kenya is set to commence after a six-month delay, reports Allan Odhiambo, Business Daily. The factory will have a capacity of 3000 tonnes cane/day and cogenerate 18 MW from bagasse. Additionally, there will be 30,000 litre ethanol production plant.

Hashil Kotecha, an official of the Kwale International Sugar Company Limited (Kiscol), which is sponsoring the project, said “We had a delay in starting the work because it took longer than expected to award the contract. We had to do a lot of due diligence on the contractors to ensure we have the best hands. We now have a contractor and preliminary works have started”.

Epco Builders has begun construction after winning the contract.

Construction of the plant, set to be run as a joint venture between Kiscol and leading Mauritian sugar producer Omnicane, was scheduled to commence in October 2011 and the factory was expected to be operational by October this year. The plant is now scheduled to come online in April 2013.

Omnican owns a 20% stake in the project. The project which will be funded 60 per cent by debt while equity from both foreign and local investors will make up the rest. Kiscol said it would rely on its own sugar estates (75%) and small-scale out-growers (25%) for the start for cane supplies. A nucleus system is considered advantageous because it allows for planning and steady supply of uniform quality cane. Bulk of the cane will come from nucleus estate (5000 ha) and the remaining from outgrowers (2500 ha).

Cane will be drip irrigated. The irrigation system will be supplied by a consortium of Ellex/Netfim (Isreal)/Amiran Kenya.

To support rural employment, only 20% of the cane production and harvesting operations will be mechanised.

As regards factory equipment, Kiscol said that it has “signed an EPC Contract with ISGEC Heavy Equipment Limited of India for sugar mill and co-generation [plant]. Tender for ethanol equipment shall be floated in January 2013.”

Russia - Tambov sugar factories commence upgrade

The sugar factories in Tambov region, namely Nikiforovsky, Znamensky and Zherdevsky, have started renovation and modernisation works to almost double their processing capacities to a combined 1 mn tonnes of beet per season, local press reports said. A financing issue for the Mordovsky sugar factory has also been solved and future plans include the construction of another sugar factory.

To get the most up-to-date answers, register for a Production Workshop led by Praj (the global ethanol technology provider) and organized by F.O. LICHTS.

To know more details, log on to: http://biofuelscee.agraevents.com

Register online at: http://biofuelscee.agraevents.com/delegate-registration/

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Obituary - Bill Hunter (1935-2012)

Bill Hunter was born in 1935 in Greenock, Scotland, a port town famous for ship building and sugar refining. There were literally dozens of small refineries reduced over the years until the closure of the only remaining Tate & Lyle Westburn Refinery in 2002.

Bill’s professional life was the sugar industry. He joined Tate & Lyle as a student in the refinery laboratory. Studies at the James Watt College, Paisley College of Technology and The Royal College of Science & Technology in Glasgow followed. The Royal College at that time (now Strathclyde University) attracted students worldwide as it was recognized as an international centre of excellence for those following a career in the sugar industry. On completion of his studies, Bill was awarded a prestigious silver medal from the City & Guilds of London, the citation was “for those who go above and beyond what is expected of them and show a true journey of progression”.

This training and education was the foundation for a career as a sugar technologist, which took him in 1958 to Redpath Refineries in Montreal and Toronto, then Utvlugt Estate in British Guiana (now Guyana), returning to Tate & Lyle in 1962 with Caroni Ltd. in Trinidad and Tobago at Usine Ste Madeleine and Brechin Castle factories. He returned to Greenock with Tate & Lyle from 1971 to 1990 working at both Walkers and Westburn Refineries.

Bill joined the firm of Fletcher Smith in Derby from 1990/2000, when he travelled more extensively through the sugar world - North, South & Central America, the Philippines, Russia, France, French West Indies, Africa and Asia commissioning equipment and undertaking a multitude of tasks associated with sugar technology.

Instead of retiring in 2000, Bill used his international experience to found ORION Process Services Ltd., a sugar process consultancy and design business, travelling even more widely, and then Alpina Orion, a parallel business partnership in Brazil, where he developed close personal and professional relationships with the people involved.

These were very successful ventures, which saw the development of cutting edge technologies and novel industrial designs, in areas such as juice clarification, evaporation and massecuite crystallization, and boiling, that he developed with Max Goehler in Brazil.

These advances are now implemented world-wide and have proven successful in lowering investment and maintenance expenses, in more efficient manufacturing processes, reduced losses resulting in increased yields. Bill was always looking to get better yields. By acting as per his expression “follow your feet”, Bill was known for his ability to identify areas of concern and to then provide local problem and location specific solutions. He mastered the ability of talking to people at all working levels in a factory, understanding them and sharing useful information despite different languages.

A scientific paper prepared by Bill will be presented at the 2012 SIT Annual Technical Meeting Conference in May in Auckland, New Zealand by his colleague Wayne Jayes.

Bill had a deep appreciation of his Scottish heritage and the disproportionate contributions of Scots in engineering and science. He had many additional interests that included bee keeping, playing Bridge, the works of Scotland’s National Poet - Robert Burns, and was a regular attender for 40 years at the Jolly Beggars Burns Club Annual Dinner which he attended on 26th January this year.

His earlier interest in sport was competitive cycling where he was successful in racing, time trials and hill climbing. In later years he enjoyed trips to watch the Tour de France. He enjoyed boxing and greyhound racing, but particularly the European football matches in Glasgow when the top teams of Glasgow Rangers and Celtic in the 1970/80’s were on a par with the very best in Europe. However, he was always loyal and supportive to the local football team Greenock Morton.

Whilst Bill had a deep interest in his work, travel and sport they were always placed in the context of his many friendships, personal and professional, and he had an abiding interest in people. He was willing to offer advice, help or support if he could, and shared his technical expertise willingly, expecting nothing in return. Above all he was a devoted family man, married to Jenny for 55 years, who supported him at all times on his journey. Bill is survived by Jenny, their two sons - William and Christopher, whose careers in science and research was a source of pride to him, daughters-in-law Laorag and Kathryn, and his beloved granddaughters Kirstine, Lauren, Rachael and Emma.

Although there had been periods of ill health in the past 4 years, in the past 6 months there were successful visits to the island of Reunion for a commissioning, and Brazil for Fenascuco then Bolivia in September 2011. Additional trips were planned for April and May this year, but Bill died suddenly and unexpectedly on 27th February 2012. His ashes are interred in the village cemetery at Inverkip.

The sugar industry was well represented at the funeral service, when former colleagues and friends travelled from far and wide to attend. Generous cash donations at the service will be donated for cancer research in the Beatson Hospital in Glasgow, where Bill had been treated. The hundreds of messages to the family from the sugar fraternity have been a great comfort to all his family.
Pol

I love old sugar books. I am fortunate to have been given a number of them by older colleagues and friends as they retired from the Sugar Milling Research Institute of Durban, South Africa. Most if not all of them contain many pages dealing with “pol”. The analytical method is rapid, simple and continues to serve the industry extremely well. Sucrose (S), glucose (G) and fructose (F) rotate the plane of polarised light; at 20°C and with a light of wavelength 589.3nm the specific rotations, \([\alpha]\), of the three sugars are +66.5º, +52.5º and -88.1º respectively (Morel du Boil and Schäffler, 1978). The amount of rotation (under fixed and specified conditions) depends on the concentration of the sugars, hence the usefulness of the method. There was considerable debate about the “fixed and specified” conditions over a period of about 40 years; finally Spencer and Meade (1948) recommended a normal weight of 26.000g. It is clear that pol is exactly equivalent to S only in pure solutions. When other optically active substances are present pol measures the overall rotation and thus gives an apparent sucrose concentration. Clerget in 1846 (Browne and Zerban, 1948) developed procedures to estimate S in the presence of other optically active substances. Further improvements were recommended by Jackson & Gillis in 1920 (Browne and Zerban, 1948).

True S balances were introduced in the S African industry in 1980; this allows pol/sucrose ratios (Brokensha and Nimeyer, 1978) in mixed juice and in final molasses to be calculated: they vary from about 0.983 to 0.997 in juice and from 0.87 to 0.98 in molasses, illustrating clearly the inaccuracies of pol balances.

It is also possible to calculate a “pol derived”, \(P_d\) (Morel du Boil and Schäffler, 1978) if it is assumed that only S, G and F are present.

Then:

\[
P_d = \%S \times 0.015 \left[ \alpha \right]_S + \%G \times \left[ \alpha \right]_G + \%F \times \left[ \alpha \right]_F
\]

where \(\%S, \%G\) and \(\%F\) are the concentrations of S, G and F, while \([\alpha]\) are functions of the specific rotations of G/F. Disagreement between the measured pol and \(P_d\) indicates the presence of optically active substances other than F or G.

It should also be noted that the specific rotation of S, F and G is affected by concentration and temperature (Bubnik et al., 1995).

Thus for S at 20°C and with light of 589.3nm:

\[
\left[ \alpha \right]_S = +66.5 + 0.01267B - 0.00376B^2
\]

where \(B\) is the mass of S per 100g solution.

So, after all, pol is not such a simple parameter. For factory control however it is difficult to find an analysis which is simpler, less expensive and more meaningful. It is also extremely precise and lends itself well to the analysis of sugars where, because of the high S content, many of the interferences mentioned above are irrelevant. This allows us to quote sugar pol values to 2 decimal places; there are not many other factory control analyses where this degree of accuracy is achievable.

References


Combination of learning-by-doing and policies are key drivers in reducing ethanol production costs in US

A new study from the University of Illinois concludes that learning-by-doing, stimulated by increased ethanol production, played an important role in inducing technological progress in the corn ethanol industry. It also suggests that biofuel policies, which induced ethanol production beyond the free-market level, served to increase the competitiveness of the industry over time.

The study, led by Professor Madhu Khanna and co-written with Xiaoguang Chen, quantifies the role that factors such as economies of scale, learning-by-doing, induced technological innovation as a result of rising input prices and trade-induced competition played in reducing the processing costs of corn ethanol in the US by 45 percent while also increasing production volumes seventeen-fold from 1983 to 2005.

“The purpose of this article was to see if we could disaggregate the extent to which various factors contributed to a reduction in cost,” Khanna said. “The existence of learning-by-doing has been empirically validated for many technologies, including other forms of renewable energy. But in the case of corn ethanol, the main contribution of this paper was to see if there were some missing variables that had affected the estimate. We found that the impact of learning-by-doing in reducing the processing costs of dry-mill corn ethanol from 1983 to 2005 was twice as high as previously estimated.”

For a retrospective analysis, a long time-series of data is necessary, the researchers say.

“The main limitation to conducting a retrospective analysis is that it takes 20 years to get 20 observations,” Khanna said. “Looking forward, what this suggests is that one can expect similar cost reductions through learning-by-doing with new technologies and that there is, in fact, a case for providing government support for nurturing new innovations in energy.”

“If we think about what it might mean for second-generation biofuels, it suggests a need to continue mandates despite all the skepticism about their efficacy,” Chen said.

“This definitely shows that government mandates that accelerate production to higher levels than would otherwise occur can induce cost reductions in the future.”

The study also concludes that the tariff on Brazilian sugarcane ethanol imports made the corn ethanol industry more competitive, but only slightly.

“On the one hand, because the tariffs protect the domestic corn ethanol industry they can induce more domestic ethanol production, which can contribute to lowering costs,” Khanna said. “But on the other hand, it also reduces competition, which reduces the incentives for the corn ethanol industry to be as efficient as it might have been otherwise. We found the latter effect offset the benefits of the larger domestic production induced by the tariff.”

The researchers also say the learning-induced cost reductions are flattening out.

“The reduction in cost is approaching its limit,” Chen said. “Additional reductions in production costs of corn ethanol, simply based on learning-by-doing, will become a lot more harder to come by because they would require very large additional production over already-high current levels. The gains from learning are largest for an infant industry in its initial stages of growth; the justification for policy support decreases as the industry expands.”

“Our estimates show that each doubling of cumulative corn ethanol production decreased its unit costs by 25%,” Khanna said. “But there’s an upper limit that has been reached to increasing corn ethanol production because of the concerns about its impact on food prices. So we may never get to that level where we see further reductions in costs as a result of an increase in total production – not because the technology has hit a wall, but simply because current policy does not allow production to expand to that level.”

Other factors such as the rising prices of energy and labour did serve to lower processing costs, but the effect was not statistically significant.

“One of the standard theories about induced innovation is that higher input prices will lead the industry to become more efficient and lower costs,” Chen said. “But we didn’t find any strong evidence of that here despite the increase in energy prices and labor costs. Instead, we found it’s really experience and learning-by-doing that’s working.”

“The demand for those inputs is not very responsive to prices, so that’s not where industry would make significant improvements,” Khanna said. “I think it’s improving the process of conversion, and improving conversion efficiencies; that’s where the real gains came from.”

The study will be published in the May issue of the journal Energy Policy.
BioMCN, first in second generation biofuels

BioMCN is the largest second generation biofuels producer in the world. With a current capacity of 250 million liters of bio-methanol per year it is already more than sufficient to fulfill the entire 2010 Dutch biofuel obligation for gasoline.

Through an innovative process, bio-methanol is made from crude glycerine - a residue resulting from processing vegetable oils and animal fats. Because bio-methanol is made from a residue, its renewable energy content is entitled to be counted twice in accordance with the Renewable Energy Directive.

In comparison to regular methanol, bio-methanol reduces CO₂ emissions by 78%.

Researchers at Virginia Bioinformatics Institute (VBI) have assembled the draft genome of a marine algae sequence to aid scientists across the US in a project that aims to discover the best algae species for producing biodiesel fuel. The results are published in Nature Communications.

Unlike crops like corn or soybeans, algae can use various water sources ranging from wastewater to brackish water and be grown in small, intensive plots on denuded land. While algae may still produce some CO₂ when burned, it can sequester CO₂ during growth in a way that fossil-fuel based energy sources cannot.

Scientists in VBI’s Data Analysis Core (DAC), Robert Settlage, and Hongseok Tae, assisted in the assembly of the genome of Nannochloropis gaditana, a marine algae that may be capable of producing the lipid yields necessary for a viable fuel source.

“Getting the data is now the easy part. What we’re doing in the DAC is enabling researchers to move beyond informatics issues of assembly and analysis to regain their focus on the biological implications of their research,” said Settlage.

Further analysis revealed that with fairly straightforward genetic modification, N. gaditana should be capable of producing biofuel on an industrial scale, which may be the wave of the future in fuel research and production.

Researchers at Virginia Bioinformatics Institute (VBI) have assembled the draft genome of a marine algae sequence to aid scientists across the US in a project that aims to discover the best algae species for producing biodiesel fuel. The results are published in Nature Communications.

Brazil - Ethanol producer invests $283 million in cane production

Usina de Acucar Santa Terezinha, an ethanol producer, plans to invest $283 million in cane production, Bloomberg reports.

The company expects to build the first phase of a 300 million real cane project in the center-west state of Mato Grosso do Sul by 2015 and will spend another 200 million reais to develop plantations for its eight existing mills, according to Sidney Meneguetti, director of Maringa, Brazil-based Santa Terezinha. Brazilian government is offering a credit line and drafting other incentives to spur investment in sugarcane production, which has dwindled since the 2008 financial crisis, Meneguetti said. Ethanol prices reached record highs in April, after supplies ran low during the annual inter-harvest season when mills shut down.

The company will start investing this year in the project, which it shelved in 2008, using funds from national development bank Banco Nacional de Desenvolvimento Economico e Social and Fundo Constitucional de Financiamento do Centro-Oeste, a government fund, Meneguetti said.

Brazil - Ethanol producer invests $283 million in cane production
Bioengineered *Escherichia coli* via a new technique boosts biodiesel production

**Significant boost in the microbial production of biodiesel has been achieved with the development of a new technique in synthetic biology by researchers with the US Department of Energy (DOE)'s Joint BioEnergy Institute (JBEI).**

This new technique - dubbed a dynamic sensor-regulator system (DSRS) - can detect metabolic changes in microbes during the production of fatty acid-based fuels or chemicals and control the expression of genes affecting that production. The result in one demonstration was a threefold increase in the microbial production of biodiesel from glucose.

“The DSRS is the first example of a synthetic system that can dynamically regulate a metabolic pathway for improving production of fatty acid-based fuels and chemicals while the microbes are in the bioreactor,” says the lead researcher Jay Keasling, CEO of JBEI.

The research is described in the paper published in *Nature Biotechnology*.

Scientific studies have consistently shown that liquid fuels derived from plant biomass are one of the best alternatives if a cost-effective means of commercial production can be found. Major research efforts to this end are focused on fatty acids - the energy-rich molecules in plant cells that have been dubbed nature’s petroleum. Fatty acids now serve as the raw materials not only for biodiesel fuel, but also for a wide range of important chemical products including surfactants, solvents and lubricants.

Fuzhong Zhang, the lead author of the paper stresses that “high productivities, titers and yields are essential for microbial production of these chemical products to be economically viable, particularly in the cases of biofuels and low-value bulk chemicals.”

Hampering microbial production of fatty acid-based chemicals has been metabolic imbalances during product synthesis.

“Expression of pathway genes at too low a level creates bottlenecks in biosynthetic pathways, whereas expression at too high a level diverts cellular resources to the production of unnecessary enzymes or intermediate metabolites that might otherwise be devoted to the desired chemical,” Zhang says. “Furthermore, the accumulation of these enzymes and intermediate metabolites can have a toxic effect on the microbes, reducing yield and productivity.”

Using the tools of synthetic biology, there have been several strategies developed to meet this challenge but these previous strategies only provide static control of gene expression levels.

“When a gene expression control system is tuned for a particular condition in the bioreactor and the conditions change, the control system will not be able to respond and product synthesis will suffer as a result,” Zhang says.

The DSRS responds to the metabolic status of the microbe in the bioreactor during synthesis by sensing key intermediate metabolites in an engineered pathway. The DSRS then regulates the genes that control the production and consumption of these intermediates to allow their delivery at levels and rates that optimize the pathway for maximum productivity as conditions change in the bioreactor.

“Nature has evolved sensors that can be used to sense the biosynthetic intermediate, but naturally-occurring regulators will rarely suffice to regulate an engineered pathway because these regulators were evolved to support host survival, rather than making chemicals in large quantity,” Zhang says.

To create their DSRS, the researchers focused on a strain of *Escherichia coli* (*E. coli*) bacteria engineered at JBEI to produce diesel fuel directly from glucose. *E. coli* is a well-studied microorganism whose natural ability to synthesize fatty acids and exceptional amenability to genetic manipulation make it an ideal target for biofuels research. In this latest work, the JBEI researchers first developed biosensors for a key intermediate metabolite - fatty acyl-CoA - in the diesel biosynthetic pathway. They then developed a set of promoters (segments of DNA) that boost the expression of specific genes in response to cellular acyl-CoA levels. These synthetic promoters only become fully activated when both fatty acids and the inducer reagent known as “IPTG” are present.

“For a tightly regulated metabolic pathway to maximize product yields, it is essential that leaky gene expressions from promoters be eliminated,” Zhang says.

“Since our hybrid promoters are repressed until induced by IPTG, and the induction levels can be tuned automatically by the FA/acyl-CoA level, they can be readily used to regulate production of biodiesel and other fatty acid-based chemicals.”

Introducing the DSRS into the biodiesel-producing strain of *E. coli* improved the stability of this strain and tripled the yield of fuel, reaching 28-percent of the theoretical maximum. With further refinements of the technique, yields should go even higher. The DSRS should also be applicable to the microbial production of other chemical products, both fatty acid-based and beyond.

“Given the large number of natural sensors available, our DSRS strategy can be extended to many other biosynthetic pathways to balance metabolism, increase product titers and yields, and stabilize production hosts,” Zhang says. “It should one day be possible to dynamically regulate any metabolic pathway, regardless of whether a natural sensor is available or not, to make microbial production of commodity chemicals and fuels competitive on a commercial scale.”
Virent and Virdia recently announced that they have been successful in converting cellulosic sugars from pine tree to drop-in hydrocarbon fuels.

Virdia’s technology releases sugars from cellulosic feedstock which is converted to fuel via Virent’s BioForming® process.

This development is part of the BIRD Energy project, a joint program commenced in January 2011 and funded by the US Department of Energy, the Israeli Ministry of National Infrastructure and the BIRD Foundation.

Jet fuel produced by the Virent process has been rigorously tested at the U.S Air Force Research Laboratory (AFRL). Tim Edwards of the Fuels Branch of the AFRL said, “This fuel passed the most stringent specification tests we could throw at it (such as thermal stability) under some conditions where conventional jet fuels would fail. This fuel is definitely worth further evaluation.”

Virdia’s CASE (Cold Acid Solvent Extraction) process encompasses a sequence of proprietary extraction and separation operations. Originally developed around the Bergius process (concentrated hydrochloric acid hydrolysis of biomass), the CASE process is claimed to achieve the highest yields in the industry, and produces high purity fractions of sugars and lignin. Its low temperature, low pressure hydrolysis coupled with its closed loops of acid recovery and solvent extraction establish it as one of the most economical and environmentally sustainable processes.

Virent’s BioForming platform utilizes a novel combination of catalytic processes to convert water-soluble oxygenated hydrocarbons derived from biomass to non-oxygenated hydrocarbons that can be used as drop-in compounds in gasoline, jet fuel and diesel fuel. Virent’s BioForming platform catalysts and reactor systems are similar to those found in today’s petroleum oil refineries and petrochemical complexes.

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Ethanol shortage in Brazil unlikely to be sorted in the near future

Brazil is struggling to produce enough ethanol to satisfy domestic demand, let alone take advantage of the huge US market where restrictions on imports for the first time since 1980 have been scrapped.

The US, the world’s largest market for the biofuel, on 1 January 2012, cut a 45 cent-a-gallon tax credit and a 54 cent-a-gallon tariff that protected local companies from foreign competition. Brazil has been unable to take advantage after output dropped 19% this season.

Investment in new sugarcane assets and plantations in Brazil plummeted to $700 million last year, from $7.84 billion in 2008, according to Salim Morsy, an analyst at Bloomberg New Energy Finance. Combination of bad weather, poor infrastructure and government bureaucracy have adversely impacted ethanol production, said Gerson Carneiro Leao, head of the National Sugar Cane Commission at the CNA agricultural confederation. “The government is to blame for the shortage of ethanol,” Leao said to Bloomberg. “Producers are indebted, taxes are exorbitant, and the red tape is stifling.”

Brazil may become a net importer of ethanol this year, with purchases of 1.66 billion litres during the 2011-2012 season exceeding exports for the first time in at least 10 years, according to Sao Paulo-based consultancy Datagro. Last year, Brazil exported 1.97 billion litres of ethanol, compared with the 5.1 billion litres shipped overseas in 2008.

To expand ethanol production, Brazil could more than double cane output to 1.2 billion metric tons a year by 2020 without destroying virgin forest, according to Unica. Even a projected increase of ethanol production by 2 billion litres for the next harvest in the Center-South, the main growing region, won’t be enough to meet domestic demand, according to Consultoria Idea, a Sao-Paulo-based consultancy.

Brazil’s fast-growing fleet of flex-fuel cars, which burn any mix of gasoline and ethanol, will cause domestic demand for ethanol to rise to 50 billion litres per year by 2018, a government study shows. Brazil would require an average of 15 new distilleries per year to reach the government’s target of producing 60 billion litres by 2021. Last year three new plants came on line.

“The opportunities that exist in Brazil today require solutions to challenges, such as the renewal of cane plantations and infrastructure bottlenecks, which increase the cost of transportation and the final product,” according to BP.

The government on 24 February outlined a 15.1 billion reais ($8.4 billion) annual investment plan through 2015 to boost cane and ethanol output. The plan must still be approved by President Dilma Rousseff and would require private sector participation.

For investors to tap new funds the government needs to tackle other obstacles such as domestic fuel price distortions, said Amaryllis Romano, an agriculture analyst at Tendencias Consultoria Integrada, a Sao Paulo-based consultant. “The ideal would be for the government to stop controlling gasoline prices,” Romano said.

Gasoline prices kept about 12% below international market levels by state-controlled oil company Petrobras have prevented producers from raising ethanol prices for competitive reasons, capping profits and slowing investment, said Guilherme Nastari, director at consultancy Datagro Consultoria.

Cane processors have instead produced more profits from sugar, which averaged 27 cents a pound in 2011, compared with 22.3 cents in 2010 and 18 cents in 2009. Taking into account the higher energy value of gasoline, ethanol is now the more expensive of the two fuels for Brazilian motorists.

Even if Brazil produces an ethanol surplus in future years it faces uncertainty over regulations in consumer countries, said Cole Gustafson, a biofuels economist at North Dakota State University in Fargo. A federal judge in December blocked California’s new fuel standard, reducing potential demand for Brazil’s low-carbon ethanol. The U.S. Environmental Protection Agency has also lowered its renewable fuel standard. “Lower federal and state requirements erode demand for Brazilian ethanol,” Gustafson said. “That gives an advantage to U.S. producers, who can deliver cheaper.”

Traders have been unwilling to commit to long-term supply contracts given these uncertainties which has kept Brazilian producers from investing to expand their export capacity, said Antonio de Padua Rodrigues, Unica’s technical director. “Those who are obliged to use ethanol in the North American market are still uncomfortable. If they wait for Brazil to increase its supply, nothing will change,” Padua said, referring to mills’ reluctance to invest in new capacity. “Maybe it’s because there are only two main producer countries.”
US - Climate change, biofuels mandate and corn price hikes

A study from Purdue and Stanford university researchers predicts that future climate scenarios may cause significantly greater volatility in corn prices in US, which would be intensified by the federal biofuels mandate.

The findings, published in the journal Nature Climate Change, show that severely hot conditions in corn-growing regions and extreme climate events that are expected to impact supply would cause swings in corn prices. Coupled with federal mandates for biofuel production, the price volatility could increase by about 50% over the period from 2020-2040 as compared to recent history.

“There could be quite a substantial increase in yield volatility,” said Professor Thomas Hertel, the lead researcher, due to increasing frequency of high temperatures in the Corn Belt. “Closer integration of the corn and energy markets through the ethanol industry could aid in buffering these shocks, but this would not occur in the presence of a mandate.”

Under current rules, the federal government requires an increasing amount of ethanol and other biofuels be produced each year and blended with gasoline. Currently 39% of the nation’s corn crop is used for ethanol, of which about one-third returns to the food system in the form of animal feed.

The study used a high-resolution climate model for the United States that takes into account climate history to produce 25-kilometer “snapshots” of the Midwest under projected future climate scenarios. Five simulations from 1950-2040 were combined to estimate future temperature extremes. Those predictions were paired with a model that uses temperature, precipitation and technology trends to predict corn yields.

The study finds that even if temperatures stay within the internationally recognized climate change target - a limit of 3.6°F above pre-industrial levels - global warming is still enough to make damaging heat waves much more common over the US Corn Belt. “Severe heat is the big hammer,” said Noah Diffenbaugh, assistant professor of earth sciences at Stanford University and a study co-author. “We find that even one or two degrees of global warming is likely to increase heat waves enough to cause much higher frequency of low-yield years, leading to greater volatility of corn prices.”

Using Purdue’s Global Trade Analysis Project model and ignoring potential adaptations, the researchers predicted US corn price volatility over the 2020-2040 period as compared with the 1980-2000 period. This increase would be further exacerbated by biofuel mandates, resulting in a further 50% increase in price volatility.

Under the projection, prices would rise in years when corn yields are reduced by extremely hot days. Ethanol plants, forced to meet the federal mandate for biofuel production, would be forced to bid up corn prices in order to meet the blend requirement, thereby exacerbating the effect of the production shortfall on livestock producers and consumers.

Finally, the study assumes that the so-called “blend wall,” which has played a key role in limiting increases in ethanol use in gasoline, would be relaxed as the automobile stock is modernized.

•
Celexion secures patent for the production of biobased difunctional alkanes

Celexion was recently granted a patent in USA for “Biological synthesis of difunctional alkanes from carbohydrate feedstocks.” The patent covers biological methods for converting renewable feedstocks into a variety of high-value chemicals with a total market value of over $10 billion.

Dr. Brian M. Baynes, CEO of CELEXION and co-inventor of the technology said “The methods disclosed in this patent enable a variety of important bulk chemicals to be synthesized from renewable starting materials using biological catalysts. The efficiency of this approach makes our products not only sustainable, but also less expensive than their petroleum-derived equivalents.”

Claims of the ’704 patent include key biosynthetic steps from common metabolic intermediates and their uses in manufacturing a family of chemicals including adipic acid, caprolactam, hexamethylenediamine, pimelic acid, and caprolactone. These chemicals are key components in a wide variety of packaging, materials, polymers, and other industrial and consumer applications.

BioViny, a new line of flexible vinyl compounds made from Dow Ecolibrium biobased plasticizers, has been developed by Teknor Apex.

BioViny compounds incorporate phthalate-free Dow Ecolibrium™ biobased plasticizers produced from plant byproducts by Dow Electrical and Telecommunications (Dow E&T), a unit of The Dow Chemical Company. Under a joint agreement, Teknor Apex has been granted the exclusive right to market in North America flexible vinyl compounds containing Dow Ecolibrium™ biobased plasticizers.

Life cycle analysis tests conducted by Dow and reviewed by a third party indicate that each ton of biovinyl compound helps the industry reduce carbon dioxide equivalent emissions by 0.7 ton, or 41%.

The commercial applications of the compounds include consumer products such as toys and footwear; medical tubing, collection bags and masks; and automotive window seals, instrument panel skins and interior and exterior trim. The company continues to develop solutions for other applications, such as wire and cable jacketing and blood bags. Teknor Apex’s BioVinyl compounds have already been chosen for certain commercial applications, including a new line of Flooring Adventures’ Tuff-Seal interlocking floor tiles; a series of shoe welting produced by Barbour Plastics; and a range of fashionable ‘flip-flop’ sandals manufactured by Okabashi Brands.

Biobased materials use expanding in automotive parts and components sector

The use of biobased materials in the manufacture of automotive parts and components have been increasing in the past few years according to a recently published study by the US-based Center for Automotive Research.

Many companies in the Great Lakes region of the US, which is the nucleus for automotive component research and manufacturing, are examining the use of biobased materials.

The study suggests that a combination of government regulations, consumer preferences and in some cases “financial savings”, is driving the increasing use of biobased materials in the automotive sector.

A particular focus of the study is the use of biobased plastics and foams in the automotive sector. Feedstocks for the production of biobased polymers include soyabean, castor bean, corn, and sugarcane. Biobased composites may be reinforced or filled using natural fibers such as hemp, flax, or sisal. Biobased materials have been tested and deployed in a number of automotive components. For example, flax, sisal, and hemp are used in door interiors, seatback linings, package shelves, and floor panels. Coconut fiber and bio-based foams have been used to make seat bottoms, back cushions, and head restraints.

For the biobased materials sector to secure increasing share of the market “biobased components must be price-neutral compared with their conventional counterparts - which is a significant challenge for a new product to overcome” the study emphasises. This is because “automakers are generally unwilling to pay a premium on parts and components.”
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Rivertop begins scaling up of glucaric acid production

Rivertop Renewables recently announced it has successfully scaled its patented process technology from the lab to pilot manufacturing. It has contracted with DTI, a custom manufacturer of fine and specialty chemical products based in Danville, Virginia, to pilot the manufacture of Rivertop’s sustainable, glucarate-based products.

Product made in this initial phase of contract manufacturing will be used to fulfill Rivertop’s commercial contracts for biobased corrosion inhibitors. Remaining volumes of manufactured product will be used by the company and its customers to develop and test glucarate applications in a myriad of other industrial and consumer markets.

Commencing in February 2012, Rivertop’s pilot manufacturing has produced many batches of glucarate-based products at approximately 850 pounds (385.5 kg) per run. DTI’s novel manufacturing technologies and flexibility enabled the accurate scaling of Rivertop’s platform oxidation process. Data derived from these and subsequent runs will enable Rivertop and DTI to scale to a capacity up to 10 million pounds (4.5 million kg) of contract-manufactured product per year. This next scale of production is projected to come online in the fourth quarter of 2012.

In addition to starting contract manufacturing, Rivertop is currently undergoing a multi-million dollar expansion of its research and development laboratories, including the construction of a semi-works facility, at its headquarters in Missoula, Montana. Successful contract manufacturing combined with the coming semi-works will enable the company to scale directly from pilot to global scale production in the coming years, removing the need for a costly demonstration plant.

The Department of Energy (DOE) has identified glucaric acid as one of the top 12 chemicals of the future made from renewable sources. Rivertop initially plans to use its glucaric acid products as an effective and cost-competitive replacement for phosphates in the multi-billion dollar markets for global detergent builders, as well as corrosion inhibitors and chelants to protect transportation and industrial infrastructure without damaging water quality. Multiple longer-term opportunities exist in the company’s research with advanced biodegradable polymers, adhesives, and other functional materials.

Rivertop’s platform process is capable of utilizing a wide variety of sugars to produce a large spectrum of green chemicals and bio-based products that possess a range of properties with applications in various markets.

EcoSynthetix expands production of biobased polymers

The Canadian-based start-up EcoSynthetix, whose patented technology produces biobased substitute to petroleum-based latex coating that gives glossy sheen to coated paper and paperboard products, recently announced that it has commissioned a new 80 million pound (36.3 million kg) production line within its existing US manufacturing facility, bringing the Company’s annualized capacity to 235 million pounds (106.6 million kg).

The production technology effectively involves a “reactive extrusion process that converts [plant-based] starch from a soluble polymer into insoluble particles, ranging in size from 50 - 150 nm.” Properties of these biopolymers are essentially similar to the emulsion polymer widely used in the industry, namely the petroleum-based Styrene Butadiene (SB) latex binder.

EcoSynthetix has called this new class of materials biolatex, which has been registered trademark. A particular novelty of biolatex is that “because you can ship it as a dried powder instead of a water-based emulsion, it greatly decreases the carbon footprint and cost of shipping the product relative to traditional latex binders that may only contain about 50% solids” according to John van Leeuwen, Chairman and CEO of the company.

The state-of-the-art 80 million pound line is comprised of the latest process automation technology. The line is also designed for flexibility, with the capability to accommodate multiple feedstocks. These attributes are expected to lead to higher throughput and result in improved margins at scale relative to the existing line in the Company’s US plant in Tennessee.

This additional capacity will support growth in the Company’s North American

Certifying bodies pass Zemea® propanediol as 100% biobased

DuPont Tate & Lyle’s Zemea® propanediol was independently reviewed by Quality Assurance International (QAI) and certified as 100% biobased by Natrue, an international non-profit organization dedicated to the promotion and protection of natural beauty and skin care products.

Feedstock used in the production of Zemea is corn sugar. Zemea is used in cosmetics and personal care market. It is an environmentally sustainable alternative to petroleum-based glycols and glycerine that is claimed to improve moisturization and has excellent aesthetic properties.

Zemea has also been approved by Ecocert, the Natural Products Association (NPA), certified 100-percent biobased by USDA, and has both kosher and halal certifications.
Bioplastics plant using Sulzer technology commences operation in Netherlands

The first polylactic acid (PLA) plant running with innovative Sulzer technology was successfully put into service by Synbra Technology in Etten Leur, the Netherlands recently. The plant was built by Sulzer Chemtech and is based on a cost-efficient polymerization process jointly developed with Purac. The plant can produce up to 5000 tons PLA per year and Synbra plans to further expand the capacity.

The construction of the plant was completed in early 2011, followed by a commissioning and testing period. The start-up has been successfully finalized and various grades of high quality PLA are being produced.

The bioplastic PLA can be used in many applications, and is produced through the ring-opening polymerization of lactide monomers. The lactide monomers are based on lactic acid produced by the fermentation of sugar or starch.

“One major advantage of PLA is its versatility. Its properties can be engineered so that it can biodegrade quickly or, alternatively, remain functional for years”, said Torsten Wintergerste, Director Polymer Technology at Sulzer Chemtech.

For long-term success in the industry, it is crucial to improve the heat resistance of current bioplastics and to make them more competitive in price. Therefore, Sulzer Chemtech and Purac have developed solutions to produce high quality heat-resistant PLA polymer based on Purac’s unique feedstocks i.e. L- and D-Lactides. With its substantially improved heat resistance the new PLA product endures temperatures of up to 180°C.

Applications in the automotive, electronics and the textile industries using this new type of heat-resistant PLA are currently under development.

The importance Sulzer puts to bioplastic developments is demonstrated by its recent decision to invest in its own 1000 ton per year PLA production plant. This will enable Sulzer to support its customers in the development of new PLA applications, both by providing samples in sizeable quantities and by demonstrating the feasibility of Sulzer’s PLA polymerization technology. The plant will be operational at the beginning of 2012 and will be located in Switzerland.

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Researchers at the UCLA Henry Samueli School of Engineering and Applied Science have for the first time demonstrated a method for converting carbon dioxide into liquid fuel isobutanol using electricity.

Today, electrical energy generated by various methods is still difficult to store efficiently. Chemical batteries, hydraulic pumping and water splitting suffer from low energy-density storage or incompatibility with current transportation infrastructure.

In a study published March 30 in the journal Science, James Liao, UCLA’s Ralph M. Parsons Foundation Chair in Chemical Engineering, and his team report a method for storing electrical energy as chemical energy in higher alcohols, which can be used as liquid transportation fuels.

“The current way to store electricity is with lithium ion batteries, in which the density is low, but when you store it in liquid fuel, the density could actually be very high,” Liao said. “In addition, we have the potential to use electricity as transportation fuel without needing to change current infrastructure.”

Liao and his team genetically engineered a lithoautotrophic micro-organism known asRalstonia eutropha H16 to produce isobutanol and 3-methyl-1-butanol in an electro-bioreactor using carbon dioxide as the sole carbon source and electricity as the sole energy input.

Photosynthesis is the process of converting light energy to chemical energy and storing it in the bonds of sugar. There are two parts to photosynthesis - a light reaction and a dark reaction. The light reaction converts light energy to chemical energy and must take place in the light. The dark reaction, which converts CO₂ to sugar, doesn’t directly need light to occur.

“We’ve been able to separate the light reaction from the dark reaction and instead of using biological photosynthesis, we are using solar panels to convert the sunlight to electrical energy, then to a chemical intermediate, and using that to power carbon dioxide fixation to produce the fuel,” Liao said. “This method could be more efficient than the biological system.”

Liao explained that with biological systems, the plants used require large areas of agricultural land. However, because Liao’s method does not require the light and dark reactions to take place together, solar panels, for example, can be built in the desert or on rooftops.

Theoretically, the hydrogen generated by solar electricity can drive CO₂ conversion in lithoautotrophic microorganisms engineered to synthesize high-energy density liquid fuels. But the low solubility, low mass-transfer rate and the safety issues surrounding hydrogen limit the efficiency and scalability of such processes. Instead Liao’s team found formic acid to be a favourable substitute and efficient energy carrier.

"Instead of using hydrogen, we use formic acid as the intermediary," Liao said. "We use electricity to generate formic acid and then use the formic acid to power the CO₂ fixation in bacteria in the dark to produce isobutanol and higher alcohols."

The electrochemical formic acid production and the biological CO₂ fixation and higher alcohol synthesis now opens up the possibility of electricity-driven biocconversion of CO₂ to a variety of chemicals. In addition, the transformation of formate into liquid fuel will also play an important role in the biomass refinery process, according to Liao.

“We’ve demonstrated the principle, and now we think we can scale up,” he said. “That’s our next step.”

Researchers at the University of Illinois led by Stephen Long have secured a $3.2 million grant from the US Department of Energy to engineer the development of oil-rich sugar-cane and sorghum. Additionally, they are aiming to develop cane that could be farmed in more northerly climes.

Researchers from the University of Florida, the University of Nebraska and the Brookhaven National Laboratory are also participating in the project.

While the researchers are calling on the latest advances in plant biotechnology and computer modelling, their approach to developing oil-rich crops will not involve engineering a new pathway, but rather enhancing “the pathway already present of triacylglyceride synthesis in both sugarcane and sorghum, by altering genes which control synthesis. Ultimately this change will be connected to gene expression systems which cause synthesis to occur in the stem, during late development, i.e. when sucrose would normally accumulate in the stem” said Long.

Regarding storage of oil deposit in cane, the researchers are targeting the same tissue that currently accumulates sucrose. A protein coat is synthesised with the oil to protect it. During the initial phase of the research over the next 18 months, the researchers are targeting an increase of 1% oil in the stem as a test of concept. If this succeeds then they will be enhancing the system by further engineering to up to 25%, says Long.

Two main hurdles anticipated by researchers are whether the plant will tolerate the oil accumulation, i.e. whether there will be any toxic effects, and targeting just the mature stem for oil storage is crucial, since diversion of energy into oil elsewhere in the plant could be damaging.

All things being equal, Long anticipates that it will be 10 years before the original proof of concept is translated into oil producing farmed cane. Further, oil yields per hectare from the engineered sugarcane and sorghum varieties are likely to be 10 greater than those currently obtained from soyabean and oilseed rape, says Long.

Researchers at the University of Illinois led by Stephen Long have secured a $3.2 million grant from the US Department of Energy to engineer the development of oil-rich sugar-cane and sorghum. Additionally, they are aiming to develop cane that could be farmed in more northerly climes.

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these surfactants are usually chemically produced. The problem is that the substances produced via such chemical processes are only suitable for a small number of applications, since they display only limited structural diversity - which is to say that their molecular structure is not very complex. Now researchers at the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB are taking a different approach: they are manufacturing surfactants using biotechnological methods, with the assistance of fungi and bacteria. “We produce biosurfactants microbially, based on sustainable resources such as sugar and plant oil,” says Suzanne Zibek, a technical biologist and engineer at the IGB in Stuttgart. The scientist and her team use cellobiose lipids (CL) and mannosylerythritol lipids (MEL) because testing has shown these to be promising for industrial application. They are produced in large quantities by certain types of smut fungus, of the kind that can affect corn plants. What is more, CL also has antibacterial properties.

What marks biological surfactants out from their synthetic competitors is their increased structural diversity. In addition, they are biodegradable, are less toxic and are just as good at loosening fats. But despite all this, to date they are used in only a few household products and cosmetics. The reason is that they are costly and difficult to produce, with low yields. One substance that has been successfully brought to market is the sophorose lipid made by Candida bombicola, which is used by a number of manufacturers as an additive in household cleaning products. This biosurfactant is produced by a yeast that is harvested from bumble-bee nectar. “If we want natural surfactants to conquer the mass market, we need to increase fermentation yields,” says Zibek. To this end, the scientists are optimizing the production process in order to bring down manufacturing costs. They cultivate the microorganisms in a bioreactor, where they grow in a continuously stirred culture medium containing sugar, oil, vitamins and minerals salts. The goal is to achieve high concentrations in as short a time as possible, so they need to encourage as many microorganisms as possible to grow. There are numerous factors with a bearing on the outcome, including the oxygen supply, the pH value, the condition of the cells, and the temperature. The composition of the culture medium itself is also crucial. It is not just a question of how much sugar and oil go into the mix, but also the speed at which they are added. “We have already achieved concentrations of 16 grams per liter for CL and as high as 100 grams per liter for MEL - with a high production rate, too,” reports the group manager.

The next step is to separate the biosurfactants from the fermentation medium and to characterize them with the help of industrial partners, determining which surfactants are suitable for use in dishwashing liquids, which are more suited to oven cleaning products, and which are ideal for use in cosmetics. The substances can finally be modified or improved at the enzymatic level. “For instance, we managed to increase water solubility. After all, the biosurfactant shouldn’t form an oily film over the surface of the dishwashing...
Plant science is key to addressing the major challenges facing humanity in the 21st Century, according to Carnegie's David Ehrhardt and Wolf Frommer. In a Perspective published online in The Plant Cell (February 2012), the two researchers argue that the development of new technology is key to transforming plant biology in order to meet human needs.

All of our food is produced by plants, either directly or indirectly via animals that eat them. Plants are a source of energy production. And they are intimately involved in climate change and a major factor in a variety of environmental concerns, including agricultural expansion and its impact on habitat destruction and waterway pollution.

What's more, none of these issues are independent of each other. Climate change places additional stresses on the food supply and on various habitats. So plant research is instrumental in addressing all of these problems and moving into the future.

For plant research to move significantly forward, Ehrhardt and Frommer say technological development is critical, both to test existing hypotheses and to gain new information and generate fresh hypotheses. If we are to make headway in understanding how these essential organisms function and build the foundation for a sustainable future, then we need to apply the most advanced technologies available to the study of plant life, they say.

They divide the technology into three categories: existing technology that isn’t being applied for all of its potential uses, new readily envisioned technology, and technology we’d like to have but don’t know how to create.

The technological overview includes expanding existing technologies such as DNA sequencing, RNA cataloguing, mass spectrometry, fluorescence-based microscopy, and electron microscopy, among many others. A key focus is on the advances possible through advanced imaging technologies.

Ehrhardt and Frommer point out that many of the most often-cited academic papers related to the development new technology, demonstrating the interest of the scientific community.

"We certainly expect that new technologies will continue to revolutionize biological research," they say. "Plant science has not often been the driver of innovation but often enough has profited from developments made in other areas."

In order to survive, plants should take up neither too many nor too few minerals from the soil. New insights into how they operate this critical balance have now been published by biologists at the Ruhr-Universität in a series of three papers in the journal The Plant Cell. The researchers discovered novel functions of the metal-binding molecule nicotianamine.

"The results are important for sustainable agriculture and also for people - to prevent health problems caused by deficiencies of vital nutrients in our diet" says Prof. Dr. Ute Krämer of the RUB Department of Plant Physiology.

All organisms need iron, zinc, and copper as nutrients. They contribute to the essential catalytic functions within the cell. Because plants are at the beginning of the food chain, sufficient content of these minerals in them is essential for the human diet. These metals are chemically very similar, making it difficult for organisms to distinguish between them.

The metal-binding molecule nicotianamine is important for iron transport in plants. Krämer has demonstrated that it also makes a major contribution to the zinc balance. "Too much zinc can poison iron-dependent processes and vice versa" the biologist explains. How much zinc is available in the cytosol depends on where the nicotianamine is stored in the cell. The membrane transport protein Zinc-Induced Facilitator1 (ZIF1) can move the metal-binding molecule from the cytosol to the vacuole - a separate area of the cell which stores substances, among other roles. Given high zinc concentrations in the cytosol, ZIF1 transports nicotianamine into the vacuole. As a consequence, zinc ions are also transported into the vacuole and thus removed from the cytosol and the internal transport routes of the plant. The zinc is now less competition for the iron, so that iron is more readily available in the cell.

For genetic reasons, plants contain very different amounts of minerals depending on their living environment. Arabidopsis halleri, for example, gathers a hundred times more zinc in its leaves than many other plants. In cooperation with colleagues from the University of Bayreuth, Krämer’s team has contributed to showing how this functions: Arabidopsis halleri produces large amounts of nicotianamine. When the researchers deactivated the synthesis of this molecule by means of genetic manipulation, the plants also transported less zinc from the roots to the leaves. Nicotianamine is therefore crucial for the high zinc concentration in leaves. "In developing countries, zinc deficiency is one of the biggest dietary risk factors for health problems" Krämer explains. "Our data may provide important clues on how to breed crops with increased zinc content."

The Bochum biologists also researched how plant cells absorb copper together with American colleagues. For this, they employed what is known as next-generation sequencing. The method they employed simultaneously decodes all messenger RNAs within a cell. This gives a complete picture of what proteins the cell should produce in what quantities. From these data, Krämer’s team identified new molecules with a critical role in the absorption of copper. The scientists demonstrated that the copper ions are first converted from the double positively charged cupric to the single positively charged cuprous form, which is essential for the following absorption in the plant. Two specific enzymes, called copper reductases, are responsible for this. "Independently of this, we have also discovered that copper deficiency in plants triggers a secondary iron deficiency - contrary to previous expectations, and very similar to human metal metabolism".
Phenolics in sugar cane juice: Potential degradation by hydrogen peroxide and Fenton’s reagent

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abstract

The presence of colour in raw sugar plays a key role in the marketing strategy of the Australian raw sugar industry. Some sugars are relatively difficult to decolourise during refining and develop colour during storage. A new approach that might result in efficient and cost-effective colour removal during the sugar manufacturing process is the use of an advanced oxidation process (AOP), known as Fenton oxidation, that is, catalytic production of hydroxyl radicals from the decomposition of hydrogen peroxide using ferrous iron. As a first step towards developing this technology, this study determined the composition of colour precursors present in the juice of cane harvested by three different methods. The methods were harvesting cane after burning, harvesting the whole crop with half of the trash extracted and harvesting the whole crop with no trash extracted. The study also investigated the degradation at pH 3, 4 and 5 of a phenolic compound, caffeic acid (3,4-dihydroxycinnamic acid), which is present in sugar cane juice, using both hydrogen peroxide and Fenton’s reagent. The results show that juice expressed from whole crop cane has significantly higher colour than juices expressed from burnt cane. However, the concentrations of phenolic acids were lower in the juices expressed from whole crop cane. The main phenolic acids present in these juices were p-coumaric, vanillic, 2,3-dihydroxybenzoic, gallic and 3,4-dihydroxybenzoic acids. The degradation of caffeic acid significantly improved using Fenton’s reagent in comparison to hydrogen peroxide alone. The Fenton oxidation was optimum at pH 5 when up to ~86% of caffeic acid degraded within 5 min.

Keywords: advanced oxidation process, caffeic acid, Fenton’s reagent, hydrogen peroxide, sugar colourants, sugar refining, phenolic acid

Los fenoles en el jugo de caña de azúcar: Su degradación potencial por el peróxido de hidrógeno y por el reactivo de Fenton

La presencia de color en el azúcar crudo juega un papel esencial en la estrategia de mercadeo de azúcar crudo de la industria de Australia. Algunos azúcares son relativamente difíciles de decolorar durante la refinación y desarrollan color durante el almacenamiento. Una nueva aproximación que podría resultar en una remoción del color, efectiva en costos, durante el proceso de refinación, está dada por el uso de un proceso de oxidación avanzado (AOP) conocido como oxidación de Fenton, que consiste en la producción catalítica de radicales hidroxilo a partir de la descomposición del peróxido de hidrógeno catalizada por el ión ferroso. Como primer paso hacia el desarrollo de esta tecnología, este estudio determinó la composición de los precursores del color presentes en la caña de azúcar cosechada por tres procedimientos diferentes. Los procedimientos fueron cosechar la caña después del quemado, cosechar el cultivo completo con extracción de la mitad de los desechos y cosechar todo el cultivo sin extraer los desechos. El estudio también investigó la degradación a pH 3, 4 y 5 de un compuesto fenólico, el ácido cafeico (ácido 3,4-dihidroxicinámico) que se encuentra presente en el jugo de la caña de azúcar utilizando tanto el peróxido de hidrógeno como el reactiv de Fenton. Los resultados mostraron que el jugo extraído de la caña cosechada en forma total tenía un color significativamente mayor que los jugos extraidos de la caña quemada. No obstante, la concentración de los compuestos fenólicos fue menor en los jugos extraidos de la caña de cosecha total. Los ácidos fenólicos principales presentes en estos jugos fueron el p-cumárico, vnilílico, 2,3-dihidroxibenzoico, gálico y 3,4-dihidroxibenzoico. La degradación del ácido cafeico mejoró significativamente utilizando el reactiv de Fenton en comparación con el peróxido de hidrógeno solo. La oxidación de Fenton fue óptima a pH 5 degradándose el ácido cafeico hasta el 86% aproximadamente dentro de los 5 minutos.

Compostos fenólicos em caldo de cana de açúcar: potencial degradação pelo peróxido de hidrogénio e reagente de Fenton

A presença de coloração em açúcar bruto desempenha um papel fundamental na estratégia de marketing da indústria do açúcar cru australiano. Alguns açúcares são relativamente difíceis de descolorar durante a refinaria e desenvolver cor durante a armazenagem. Uma nova abordagem que poderia resultar na remoção de cor eficiente e econômica durante o processo de fabricação de açúcar é o uso de um processo de oxidação avançado (AOP), conhecido como oxidação de Fenton, isto é, produção catalítica de radicais hidroxila resultantes da decomposição de peróxido de
Introduction

One of the most important parameters in sugar quality is colour. Australian raw sugars are considered to be of high quality. This plays a key role in the marketing strategy of the Australian raw sugar industry. However, some raw sugars produced both in Australia and overseas are relatively difficult to decolourise and can develop colour during storage.

The costs of refining are directly proportional to the amount of colouring matter in raw sugar, possibly decreasing the market value of raw sugar. In sugar refining, colour removal comes at a major cost, hence the sugar refiners require raw sugars that are easy to decolourise and have low impurity loading.

The formation of colour in raw sugar is a common problem in both sugar cane and sugar beet industries (Paton, 1992). The colorants that are difficult to decolourise are mainly hydrophobic and they cover a wide range of molecular weights. They exhibit an anionic behaviour at high pH levels. Their behaviour and reactivity at various stages of the sugar manufacturing process are extremely complex. They can participate in a number of reactions which lead to the formation of polymeric substances, highly coloured compounds and iron metal complexes. A reduction of colour in sugar or a cheap and effective method of removal in processing would lead to lower refining costs. There are few known simple processes in the raw sugar manufacturing process, apart from the crystallisation process, that can effectively and economically reduce colour. The options that are in current use in Australia for colour removal in raw sugar include double purging (washing) of sugar crystals and modification of crystallisation boiling schemes. These treatment procedures involve rejection of colour during or after the crystallisation process but are less effective with highly coloured raw sugars.

Phenolic compounds are well known to be colour precursors leading to the formation of coloured compounds with iron and copper and to oxidise high molecular weight coloured polymers. They relate to the tendency of sugar to darken in storage and are not removed during clarification.

On the basis of the colour profile across the sugar manufacturing stage, to reduce colour in raw sugar, colour removal strategies should be targeted at mixed juice and/or juices during the evaporation stage.

Chemical additives such as hydrogen peroxide (H₂O₂), ozone and coagulants have been used to decolourise sugar process streams (Madsen, 2006; Mane et al., 1998; Mane et al., 1992; Mane et al., 2000; Moodley et al., 1999; Patel and Moodley, 1991; Saska, 2007). Their use has not been widely implemented due to limited benefits.

A recent study by Pala and Erden (2005) has demonstrated the potential of the Fenton oxidation process to decolourise molasses. Madsen and Day (2010) demonstrated the removal of phenolic and other colourants from raw juice using endogenous proteins as well as ferric iron (Fe³⁺) as an oxidative catalyst via cold liming. The treatment produced clarified juice with up to 70% lower colour than juice produced by hot liming.

This study builds on these works by examining the degradation of a model phenolic compound, caffeic acid with ferrous iron (Fe²⁺) and H₂O₂. The project also determined the composition of phenolic compounds present in burnt sugar cane juices and juices expressed from whole crop cane with half of the trash extracted and whole crop cane with trash not extracted.

Decolourisation using advanced oxidation processes

The use of oxidative decolourants to decolourise sugar process streams and/or raw sugars has received increasing interest in recent times. They are strongly oxidising chemicals which include H₂O₂, ozone and hypochlorite. Chlorinated compounds are not recommended because of toxicological concerns surrounding the production of unwanted by-products in juice (Davis, 2001).

Hydrogen peroxide

The reason for the difference between the action of oxidative chemicals and other decolourisation techniques lies in the reaction mechanism pathway. Oxidants destroy colour by cleaving unsaturated bonds (i.e. conjugated species) (Riffer, 2000).

Ferrous iron salts (Fenton’s reagent)

Advanced oxidation processes (AOPs) are based on the generation of hydroxyl radicals (•OH). In these processes, the oxidation strength of H₂O₂ is enhanced by combining with acids, transition metal salts or UV-light to form •OH and hydroxyl ions (Dwyer et al., 2008).

An example of this is the activation of H₂O₂ using Fe²⁺, typically referred to as the Fenton reaction. The Fenton reaction involves the generation of •OH through the catalytic decomposition of H₂O₂ using Fe²⁺ as the catalyst under acidic conditions.

The use of Fenton’s reagent is more attractive in comparison to other AOPs for various reasons:

- reagents are relatively cheap and available commercially
- hydrogen peroxide decomposes to H₂O and O₂ spontaneously
iron is present in sugar process streams
• equipment requirements and operating costs are minimal
• complete oxidative destruction of colourants to harmless compounds (viz. H₂O and CO₂) is achieved (Neyens and Baeyens, 2003).

The use of Fenton’s reagent and H₂O₂ for the oxidative degradation of caffeic acid (Figure 1) in aqueous solution was investigated.

**Materials and methods**

**Reagents and solvents**

Analytical grade phenolic acids were purchased commercially from Sigma-Aldrich (St. Louis, MO, USA). Analytical grade hydrogen peroxide (30% w/v) and ferrous sulfate heptahydrate were obtained from Ajax Finechem (Seven Hills, NSW, Australia). Solvents obtained from Merck (Darmstadt, Germany) were HPLC grade.

**Juice sampling**

First expressed juice (FEJ) from burnt cane was obtained from the processing lines at Condong Mill, NSW, Australia. The FEJ of whole crop cane was obtained by harvesting whole crop in the field and expressing juice with a laboratory hammer mill. Both FEJs were obtained during the crushing season in 2009.

Primary juices (PJs) from burnt cane and 50% whole crop cane were obtained from Condong Mill during the crushing season in 2010. All juices were stored at -22°C. In total, four juices (2 FEJs and 2 PJs) were analysed in this study.

The following analyses of the four juice samples are unrelated and not comparable. The results obtained provide an insight on the levels of colour and phenolic compounds present in each juice type.

**Colour analyses of sugar cane juices**

Colour of each juice sample was determined at pH 7 by measuring the absorbance at 420 nm in 1 cm cells. Samples were diluted to an appropriate absorbance range and membrane filtered (0.45 µm) before adjusting the pH using 0.1 M and 0.01 M NaOH solutions respectively. The colour was calculated as:

*Figure 1. Molecular structure of caffeic acid (C₉H₆O₄)*
Colour = \frac{1000 \times A_{220}}{\text{Cell Length (cm)} \times \text{Sucrose Concentration (g/ml)}}

Readings were performed in triplicate for each juice sample and reported as an average of the three readings. The precision of the experimental results is expressed as the relative standard deviation:

\% \text{RSD} = \frac{\text{Standard Deviation of triplicate readings}}{\text{Average of triplicate readings}} \times 100

The impurity of juice samples is expressed as the ratio of impurity to water (I/W) content as:

I/W = \frac{\% \text{ Total Solids} - \text{Sucrose}}{100 - \% \text{ Total Solids}}

The brix of the samples was measured at ambient temperature using a Bellingham + Stanley RFM 342 refractometer accurate to ± 0.01 °Bx.

Extraction of phenolic acids from sugar cane juices

Juices were treated via alkaline hydrolysis. The individual mixtures were neutralised and extracted with diethyl ether (3 × 20 mL).

The individual dried residues were weighed and dissolved in water (10 mL). The solutions were membrane filtered (0.45 µm) prior to evaluation by high-performance liquid chromatography.

High-Performance Liquid Chromatography (HPLC) conditions and analysis

The HPLC method used was similar to a previously reported method for the determination of phenolic acids in apple and pear juices (Schieber et al., 2001). The assignment of eluted peaks was confirmed by spiking the juices with known phenolic acids and 5-hydroxymethylfurfural (HMF) and by comparing retention times to a standard mixture of nine phenolic acids and HMF.

A set of five standard solutions was prepared for each compound and injected to generate a five-point calibration curve separately.

The calibration curves were linear with a R^2 ≥ 0.9985. The peak areas of the target compounds were within the linear range of the calibration curve. The relative standard deviation (% RSD) for triplicate injections of each standard for a set of five standard solutions was less than 5%.

Degradation efficiency of caffeic acid using H₂O₂ and Fenton’s reagent

Caffeic acid solution (10,000 ppm) was prepared by dissolving caffeic acid in a degassed solvent consisting of absolute ethanol and 0.056 µS/cm high purity water (1:1, v/v). Aqueous Fe²⁺ solution (50,000 ppm) was prepared by dissolving solid FeSO₄.7H₂O in high purity water. An H₂O₂ solution was prepared from stock analytical grade H₂O₂ and high purity water.

The solution (5000 ppm) was standardised by iodometric titration. In order to establish the stoichiometry that exists between caffeic acid (200 ppm), Fe²⁺ (200 ppm) and H₂O₂ (100 and 400 ppm), the materials were used to prepare a series of solutions according to the sample matrix given in Table 1.

The procedure for the addition of the Fenton’s reagent can be described as follows: (a) adjusting the pH to 3, 4 or 5 of the caffeic acid solution (b) addition of FeSO₄ solution (c) addition of H₂O₂ and (d) the reaction allowed to run for up to 30 min at ambient temperature with agitation. The procedure for the addition of H₂O₂ without Fe²⁺ was identical with the exception that the reaction was allowed to run for up to 60 min. The pH was measured using a Radiometer Analytical MeterLab PHM 220 pH-meter. Aliquots (1 mL) were taken at 5 min intervals, diluted 10-fold and analysed by UV-visible spectrometry. Absorbance measurements were conducted on a GBC Cintra 40 double beam UV-visible spectrometer for the wavelengths ranging between 190 nm and 800 nm.

Results and discussion

Colour analyses of juices

Colour is conventionally measured at pH 7. Flavonoids and phenolic compounds are pH sensitive and their colour profile increases greatly from minimal colour in untreated mixed juice and FEJ (at pH 4–5) up to near-maximum colour at pH 9 (Paton, 1992).

Therefore, colour measured at the ideal pH of 7 or higher would provide satisfactory measurement of the presence of flavonoids and phenolic compounds. The colour of Condong Mill juices is presented in Table 2.

Table 1. Volumes of reagents used in the degradation reaction studies

<table>
<thead>
<tr>
<th>Sample*</th>
<th>Water (µL)</th>
<th>Caffeic acid (µL)</th>
<th>Fe²⁺ (µL)</th>
<th>H₂O₂ (µL)</th>
<th>[H₂O₂] (ppm)</th>
<th>Total (µL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank A</td>
<td>49,000</td>
<td>1000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>50,000</td>
</tr>
<tr>
<td>Exp. #1</td>
<td>48,000</td>
<td>1000</td>
<td>0</td>
<td>1000</td>
<td>100</td>
<td>50,000</td>
</tr>
<tr>
<td>Exp. #2</td>
<td>45,000</td>
<td>1000</td>
<td>0</td>
<td>4000</td>
<td>400</td>
<td>50,000</td>
</tr>
<tr>
<td>Blank B</td>
<td>48,880</td>
<td>1000</td>
<td>200</td>
<td>1000</td>
<td>0</td>
<td>50,000</td>
</tr>
<tr>
<td>Exp. #3</td>
<td>47,800</td>
<td>1000</td>
<td>200</td>
<td>1000</td>
<td>100</td>
<td>50,000</td>
</tr>
<tr>
<td>Exp. #4</td>
<td>44,800</td>
<td>1000</td>
<td>200</td>
<td>4000</td>
<td>400</td>
<td>50,000</td>
</tr>
</tbody>
</table>

*Blank solutions A and B are for H₂O₂ and Fenton’s reagent reactions respectively.

Table 2. Colour of various sugar cane juices recorded at pH 7

<table>
<thead>
<tr>
<th>Colour</th>
<th>50% whole crop PJ</th>
<th>Burnt cane PJ</th>
<th>Whole crop FEJ</th>
<th>Burnt cane FEJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour (IU on dry solids)</td>
<td>152,000</td>
<td>84,800</td>
<td>69,600</td>
<td>53,500</td>
</tr>
<tr>
<td>C/I ratio</td>
<td>58,300</td>
<td>27,400</td>
<td>40,900</td>
<td>9070</td>
</tr>
</tbody>
</table>

*% RSD was less than 0.7%. C/I = Colour (on dry solids)-to-impurity ratio.
Analysis of phenolic acids

The phenolic compounds separated from cane juice are shown in Figure 2. Baseline separation was achieved for all identified components. The \( m \)- and \( o \)-isomers of coumaric acid were not detected in any of the analysed cane juice extracts. The elution order of the phenolic compounds was consistent with previous studies under different HPLC conditions with the exception of 2,3-dihydroxybenzoic acid and chlorogenic acid (Curtin and Paton, 1980).

The concentrations of each compound varied with the juice type (Table 3). The concentrations of phenolic acids in whole crop juices were substantially lower than burnt cane juices. This is probably due to the valorisation of lignin (thermal degradation of lignin and biomass to produce profitable products) during cane burning.

Higher amounts of HMF were identified in both PJ and FEJ of burnt cane juices compared to whole crop juices (Table 3). This may be because of the dehydration of sugars (particularly reducing sugars) to HMF (Huber et al., 2006) as a result of high temperatures generated during burning of cane prior to harvesting. To our understanding, the quantification of HMF in Australian PJ and FEJ using this method has not been described in the literature. Caffeic acid concentrations in each juice sample were relatively lower than other phenolic acids.

Higher concentrations of phenolics are present in PJs compared to FEJs (Table 3). This is probably due to the decomposition of certain flavonoids followed by oxidation of the intermediate products and further degradation of lignin products at relatively higher processing temperatures of PJ.

The concentrations of phenolic acids are considerably higher than those previously described by Curtin and Paton (1980). Table 4 shows a comparison of the phenolic acid composition for juices from Table 3 in terms of ppm on juice, to those of Curtin and Paton (1980). The differences between the two sets of data may be related to differences in the cane varieties or to differences in the analytical procedures used for phenolic acid analysis.

As evident from Tables 2, 3 and 4, the juices expressed from whole crop contain higher colour but lower phenolics than the juices expressed from burnt cane. It is therefore deduced that that the whole crop juices contain a higher proportion of cane pigments.

Degradation of caffeic acid by \( \text{H}_2\text{O}_2 \) and Fenton’s reagent

The average concentration of caffeic acid in the juices was \(~10\) ppm, although a caffeic acid concentration of 200 ppm was chosen for the degradation studies in order to account for other phenolics and colour precursors (amines and amino acids) present in cane juice.

Figure 3 shows the degradation of caffeic acid with a 100 ppm dosage of \( \text{H}_2\text{O}_2 \) at pH 3 at 0, 30 and 60 min. Two isosbestic points at 292 nm and 320 nm are attributable to the deprotonated caffeate anion (\( \text{C}_9\text{H}_7\text{O}_4^- \)) and the caffeic acid molecule (\( \text{C}_9\text{H}_8\text{O}_4 \)) respectively (Cornard et al., 2006). These points were present in reaction mixtures containing caffeic acid and Fenton’s reagent at pH 3, 4 and 5.

At pH 3 and 60 min, \( 16.5\% \) caffeic acid was degraded. At pH 4 and 5, there was no observable caffeic acid degradation. At a higher \( \text{H}_2\text{O}_2 \) dosage of 400 ppm, no reduction in absorbance was noticeable at either isosbestic points even at pH 3. There appeared to be some degradation occurring at lower wavelengths but this was not conclusive. It is speculated that with the addition of 400 ppm of \( \text{H}_2\text{O}_2 \) after initial reactions between the hydroxyl radicals and caffeic acid, there were subsequent recombination reactions.

The degradation of caffeic acid with the Fenton’s reagent monitored at 320 nm is shown in Figure 4. The reaction was virtually complete within 5 min. Within 30 min, \( 85.8\% \) of caffeic acid was destroyed upon addition of 200 ppm \( \text{Fe}^{2+} \) and 400 ppm \( \text{H}_2\text{O}_2 \) at pH 5, in which most of the degradation took place within 5 min. At lower pH, the degradation of caffeic acid was less with \( 61.7\% \) and \( 66.4\% \) degradation for pH 3 and 4 respectively. The degradation of the deprotonated caffeate anion was also observed. The degradation ratio of the neutral and anionic forms

**Figure 2.** Separation of a typical mixture of phenolic compounds in the FEJ of burnt cane by HPLC with UV detection at 280 nm

A = gallic acid (tentative); 1 = HMF; 2 = 4-hydroxybenzoic acid; 3 = chlorogenic acid; 4 = vanillic acid; 5 = caffeic acid; 6 = 2,3-dihydroxybenzoic acid; B = 3,4-dihydroxybenzoic acid (tentative); 7 = p-coumaric acid; 8 = ferulic acid
was 1:1, hence the Fenton’s reagent is capable of attacking both forms of caffeic acid. A similar trend was observed when a lower dosage of H$_2$O$_2$ was used with less than 70% degradation observed within the studied pH region.

The degradation trends were similar for both 100 ppm and 400 ppm H$_2$O$_2$ dosages with the latter having a larger decrease in absorbance. A faster degradation rate was observed at pH 5 for both H$_2$O$_2$ dosages despite a higher initial absorbance. The higher initial absorbance is attributable to the chelating ability of ferrous iron on caffeic acid to produce coloured complexes (Smith, 1983).

No other prominent peaks were observed across the spectral wavelength range during the course of both experiments. This suggests that the degradation products formed from the use of Fenton’s reagent are colourless compounds or low molecular weight compounds with a weak or no UV-chromophore.

**Conclusions**

Phenolic acids present in different juices types were determined by HPLC analysis. The concentrations of identified phenolic acids were substantially higher in burnt cane juices than in whole crop juices, though the overall juice colour (measured at 420 nm at pH 7) was higher in the latter juices. The Fenton’s reagent is an effective oxidant for the degradation of caffeic acid compared to H$_2$O$_2$.

**Acknowledgements**

The work was funded by Sugar Research Limited (SRL), the Sugar Research and Development Corporation (SRDC) and the Queensland University of Technology (QUT) through the Sugar Technology Innovation Scholarship. The authors wish to thank the management and production staff at Condong Mill.

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**References**


Dwyer, J., Kavanagh, L. and Lant, P. (2008) The degradation of

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**Table 3.** HMF and phenolic compounds isolated from various sugar cane juice samples (ppm on dry solids)^†^  

<table>
<thead>
<tr>
<th>Compound</th>
<th>50% whole crop PJ</th>
<th>Burnt cane PJ</th>
<th>Whole crop FEJ</th>
<th>Burnt cane FEJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMF</td>
<td>330</td>
<td>6550</td>
<td>261</td>
<td>1380</td>
</tr>
<tr>
<td>4-Hydroxybenzoic acid</td>
<td>7030</td>
<td>18,800</td>
<td>322</td>
<td>5300</td>
</tr>
<tr>
<td>Chlorogenic acid</td>
<td>4710</td>
<td>44,400</td>
<td>358</td>
<td>23,000</td>
</tr>
<tr>
<td>Vanillic acid</td>
<td>13,900</td>
<td>27,800</td>
<td>592</td>
<td>9350</td>
</tr>
<tr>
<td>Caffeic acid</td>
<td>11,300</td>
<td>24,300</td>
<td>633</td>
<td>9480</td>
</tr>
<tr>
<td>2,3-Dihydroxybenzoic acid</td>
<td>11,700</td>
<td>24,900</td>
<td>634</td>
<td>9020</td>
</tr>
<tr>
<td>p-Coumaric acid</td>
<td>14,000</td>
<td>95,900</td>
<td>995</td>
<td>23,600</td>
</tr>
<tr>
<td>Ferulic acid</td>
<td>7130</td>
<td>13,700</td>
<td>477</td>
<td>7310</td>
</tr>
</tbody>
</table>

*% RSD < 5%  ^Cane juice data based from (Curtin and Paton, 1980); nq, not quantified

**Table 4.** HMF and phenolic compounds isolated from various sugar cane juice samples (ppm on juice)^†^  

<table>
<thead>
<tr>
<th>Compound</th>
<th>50% whole crop PJ</th>
<th>Burnt cane PJ</th>
<th>Whole crop FEJ</th>
<th>Burnt cane FEJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMF</td>
<td>1.5</td>
<td>2.6</td>
<td>0.2</td>
<td>3.3</td>
</tr>
<tr>
<td>4-Hydroxybenzoic acid</td>
<td>5.8</td>
<td>7.6</td>
<td>4.9</td>
<td>4.1</td>
</tr>
<tr>
<td>Chlorogenic acid</td>
<td>25.3</td>
<td>17.9</td>
<td>3.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Vanillic acid</td>
<td>10.3</td>
<td>11.2</td>
<td>9.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Caffeic acid</td>
<td>10.4</td>
<td>9.8</td>
<td>7.9</td>
<td>8.1</td>
</tr>
<tr>
<td>2,3-Dihydroxybenzoic acid</td>
<td>9.9</td>
<td>10.0</td>
<td>8.2</td>
<td>8.1</td>
</tr>
<tr>
<td>p-Coumaric acid</td>
<td>26.0</td>
<td>38.7</td>
<td>9.8</td>
<td>12.7</td>
</tr>
<tr>
<td>Ferulic acid</td>
<td>8.0</td>
<td>5.5</td>
<td>5.0</td>
<td>6.1</td>
</tr>
<tr>
<td>3,4-Dihydroxybenzoic acid (tentative)</td>
<td>nq</td>
<td>nq</td>
<td>nq</td>
<td>nq</td>
</tr>
<tr>
<td>Gallic acid (tentative)</td>
<td>nq</td>
<td>nq</td>
<td>nq</td>
<td>nq</td>
</tr>
<tr>
<td>Sinapinic acid</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*% RSD < 5%  ^Cane juice data based from (Curtin and Paton, 1980); nq, not quantified
dissolved organic nitrogen associated with melanoidin using a UV/H₂O₂ AOP. Chemosphere 71: 1745-1753.


Experience with continuous crystallization of refined sugar at United Sugar, Jeddah

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* Contact author: Email: avawda@savola.com

abstract

While most other unit operations have moved to continuous operation, refined sugar pan boiling is generally conducted in batch pans. The vertical continuous pan at United Sugar refinery in Jeddah has been successfully operating since 2007. It is possible to compare batch pan operation with continuous pan operation, as both systems operate in parallel. Generally speaking, the merits of a continuous process over a batch process are follows: Better plant utilization; higher operating and energy efficiency; and simpler process control. This paper examines the performance of the Jeddah continuous pan on the basis of: design features; heat and mass transfer; operating experience; crystal size distribution; sugar quality; fouling and encrustation; and instrumentation and control.

Keywords: CDR Crystal Deposition Ratio, continuous pans, crystal size distribution, CV Coefficient of Variation, encrustation, HTC Heat Transfer Co-efficient, refined sugar, super saturation, VKT

Introduction

Over the last sixty years the sugar industry has gradually moved from batch to continuous processes. Raw sugar factories especially have adopted continuous boiling since the nineties and realised real benefits from these processes. However, concerns over perceived problems, mainly associated with low cycle times, have resulted in only a 30% application to A Massecuite boilings.

In sugar refining, these same concerns have resulted in a reluctance to move to continuous white boiling. Some of the perceived reasons for the reluctance to adopt the continuous boiling process in refineries are as follows:

1. Low productivity
2. Poor coefficient of variation (CV)
3. Higher capital cost

Despite the above, refinery continuous pans have made some inroads due to the application of technology applied to mitigate some of the disadvantages. United Sugar Company had planned a capacity expansion in 2005. It was decided to take advantage of this opportunity to expand and simultaneously improve the factory steam economy.
Reasons for selecting a continuous pan

The required expansion from 2500 tons per day (tpd) to 3000 tpd, with later 3500 and 4000 tpd, was approved in 2005. During the early stage of the design, the technical team conducted a survey of the capacity of the process units and identified deficiencies in various unit operations. It became obvious that increasing the refinery capacity using conventional technology would require the following additional equipment:

1. Steam generation
2. Desalination
3. Water demineralization
4. Batch pans
5. Strike receivers
6. Evaporators
7. Condensers

Being inside the port area, the refinery has very limited available space and the conventional design was not acceptable from both a cost and available space point of view.

After considering the need for improving energy efficiency and selecting equipment that was space friendly, a vertical continuous pan was considered to be the best solution (Figure 1).

The vertical continuous pan has the following advantages:

1. Being a weather-proof tower it could be located outside the building thereby realising savings in civil and steel structure. The 5.6m diameter requires a small pan foot print. Compare this to five batch pans located side by side.
2. Requiring low calandria pressure, it could operate on V1 vapour to improve over-all steam economy.
3. Producing refinery massecuite in a continuous pan would reduce the use of batch pans, thus minimising the cyclic pressure fluctuations in the exhaust steam range and the central vacuum system.
4. The attractiveness of adding a fifth cell in the future. This is more cost effective than installing an oversized pan. Over sizing has the disadvantage of wasted capital and the increased retention results in adverse quality of massecuite.
5. Having independent cells, means that different calandria pressures could be employed. In fact, the calandria steam can be sourced from different origins if necessary.

By far the most attractive argument in favour of the VKT was the lower over-all capital and operational cost. The batch pan system, with its buildings, batch pans and crystallizers cost 37% more. This does not take into account the additional equipment required for steam generation and condensing.

Design features

The vertical continuous pan (VKT) can simply be described as a number of batch pans stacked one on top of each other (Table 1). The pan boiling process is carried out by continuously feeding the seed crystals and sugar syrup to the unit, while withdrawing the final massecuite from the last chamber.

Table 1. Comparison of a VKT cell and a batch pan at USC

<table>
<thead>
<tr>
<th></th>
<th>Batch pan</th>
<th>VKT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pan diameter m</td>
<td>4.72</td>
<td>5.60</td>
</tr>
<tr>
<td>Down take diameter m</td>
<td>1.78</td>
<td>2.40</td>
</tr>
<tr>
<td>Diameter ratio</td>
<td>0.38</td>
<td>0.43</td>
</tr>
<tr>
<td>Tube diameter mm</td>
<td>101.60</td>
<td>101.60</td>
</tr>
<tr>
<td>Distance between tube plates m</td>
<td>0.95</td>
<td>1.30</td>
</tr>
<tr>
<td>Massecuite height above calandria m</td>
<td>2.25</td>
<td>0.40</td>
</tr>
<tr>
<td>Heating surface area m²</td>
<td>353.00</td>
<td>636.00</td>
</tr>
<tr>
<td>Heating surface to volume ratio</td>
<td>5.90</td>
<td>12.00</td>
</tr>
</tbody>
</table>

Table 2. Specification of the VKT

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of compartments</td>
<td>4</td>
</tr>
<tr>
<td>Massecuite volume per compartment</td>
<td>50m²</td>
</tr>
<tr>
<td>Product retention time, at full capacity</td>
<td>2.1hr</td>
</tr>
<tr>
<td>Diameter of pan</td>
<td>5.6m</td>
</tr>
<tr>
<td>Heating surface of each chamber</td>
<td>636m²</td>
</tr>
<tr>
<td>Overall cylinder height</td>
<td>31m</td>
</tr>
</tbody>
</table>

The pan shell is 5.6m in diameter constructed of carbon steel. The massecuite contact area is SS304 clad up to 1000mm above the calandria. Each of the four chambers are similar to ordinary batch pans (Table 2).

Incondensable gasses are extracted as in normal batch pans.
In this installation the incondensable gasses are vented to the vacuum main because the V1 vapour used for heating is sub-atmospheric.

The entrainment prevention system consists of a vapour box containing baffles which change the direction of vapour, collecting droplets on impact.

Each compartment is provided with an agitator, the first two compartments with three bladed impellers and the last two with five bladed propeller stirrers (Figures 2 and 3). The first two are driven by a 37kW motor, while the last two compartments are served by 90kW motors. Final brix control in chamber 4 is provided by amps draw-off of the stirrer motor. Chamber 3 also has a 90kW motor in the event that compartment is off line for cleaning.

**Heat and mass transfer**

The function of a pan is to transform sucrose from a liquid phase to a solid phase. This is accomplished in batch and continuous pans by maintaining a super saturation driving force by evaporation. The application of heat in continuous pans is comparatively gentle compared to that in batch pans.

Typical evaporation rate and crystal deposition rates are shown in Table 3.

**Heat transfer**

Modern vacuum pans have evolved over the years and today most pans, both batch and continuous, have vertical tubes and agitators.

The relationship between massecuite height and temperature difference between heating steam and vapour is shown by Austmeyer 3 in Figure 4.

It shows that with a low massecuite height, good HTC is achieved. It also shows that this can be achieved with a low temperature difference (deltaT) between calandria heating steam and massecuite.

The lower deltaT for the continuous pan compared to the batch pans, permits the use of bled vapour and the ensuing energy savings that comes with it. However, this lower deltaT comes at a price, in that the evaporation rate is lower per unit area compared to that in batch pans (Table 4).

**Table 3. Comparative heat and mass transfer performance data**

<table>
<thead>
<tr>
<th></th>
<th>Continuous pan</th>
<th>USC batch pan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation rate kg/m²/h</td>
<td>13</td>
<td>35</td>
</tr>
<tr>
<td>Crystal deposition rate kg/m³/h</td>
<td>320</td>
<td>375</td>
</tr>
<tr>
<td>OHTC W/m²/C</td>
<td>470</td>
<td>680</td>
</tr>
<tr>
<td>Temperature difference calandria-vapour</td>
<td>31</td>
<td>58</td>
</tr>
</tbody>
</table>

**Figure 2.** The three bladed impeller found in chambers 1 and 2

**Figure 3.** The five bladed impeller found in chambers 3 and 4

**Figure 4.** Graph showing the influence of massecuite height on OHTC
The VKT and batch pans at USC have an average evaporation rate of 12 kg/m² and 40 kg/m², respectively. Continuous pans in general have more surface area which compensates for this evaporation difference. The heating surface to volume ratio for both types of pan is shown in Table 1.

Refinery batch pans are fast crystallizing units because of the high purity product being boiled. The rate limiting factor is often said to be the evaporation rate which is much higher in batch pans than in continuous pans. The situation at USC is as follows:

<table>
<thead>
<tr>
<th>pan type</th>
<th>Total volume m³</th>
<th>Total massecuite output MT/h</th>
<th>Massecuite output/volume MT/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch pan</td>
<td>240</td>
<td>180</td>
<td>0.75</td>
</tr>
<tr>
<td>Continuous pan</td>
<td>260</td>
<td>190</td>
<td>0.73</td>
</tr>
</tbody>
</table>

The seed pan volume (60m³) must also be included to the VKT volume. Table 5 shows that the difference between batch pans and continuous pans is negligible for high purity refinery boiling. Since the centrifugal yield is higher in the continuous pan compared to the batch pan, this small difference is of no consequence.

**Table 4. Typical calandria steam pressures**

<table>
<thead>
<tr>
<th>Units</th>
<th>Batch pan</th>
<th>Batch pan</th>
<th>Batch pan</th>
<th>Batch pan</th>
<th>CVP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HR</td>
<td>USC</td>
<td>T+L</td>
<td>USCE</td>
<td>VKT</td>
</tr>
<tr>
<td>Calandria pressure</td>
<td>Bara</td>
<td>5.00</td>
<td>2.20</td>
<td>1.90</td>
<td>1.50</td>
</tr>
<tr>
<td>Vapour pressure</td>
<td>Bara</td>
<td>0.25</td>
<td>0.25</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>Boiling cycle time</td>
<td>Hrs</td>
<td>1.50</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Calandria type</td>
<td>Ribbon</td>
<td>Tubular</td>
<td>Tubular</td>
<td>Tubular</td>
<td>Tubular</td>
</tr>
<tr>
<td>Gross dT °C</td>
<td>85</td>
<td>58</td>
<td>56</td>
<td>48</td>
<td>29</td>
</tr>
</tbody>
</table>

**Table 5. Productivity comparison batch pan vs continuous pan**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Batch pan</th>
<th>Continuous pan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pan volume m³</td>
<td>240</td>
<td>260</td>
</tr>
<tr>
<td>Total massecuite output MT/h</td>
<td>180</td>
<td>190</td>
</tr>
<tr>
<td>Massecuite output/volume MT/m³</td>
<td>0.75</td>
<td>0.73</td>
</tr>
</tbody>
</table>

**Table 6. Progressive crystal growth and retention time**

<table>
<thead>
<tr>
<th>MA mm</th>
<th>Retention time minutes</th>
<th>Massecuite flow t/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed pan</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Cell 1</td>
<td>0.47</td>
<td>47</td>
</tr>
<tr>
<td>Cell 2</td>
<td>0.54</td>
<td>34</td>
</tr>
<tr>
<td>Cell 3</td>
<td>0.62</td>
<td>27</td>
</tr>
<tr>
<td>Cell 4</td>
<td>0.68</td>
<td>22</td>
</tr>
</tbody>
</table>

**Table 7. Design performance vs actual**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BMA</th>
<th>USC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massecuite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass flow rate t/h</td>
<td>190.00</td>
<td>191.00</td>
</tr>
<tr>
<td>Brix %</td>
<td>90.50</td>
<td>89.70</td>
</tr>
<tr>
<td>Mean crystal size mm</td>
<td>0.60</td>
<td>0.68</td>
</tr>
<tr>
<td>Seed magma</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass flow rate t/h</td>
<td>51.60</td>
<td>65.00</td>
</tr>
<tr>
<td>Dry matter %</td>
<td>89.00</td>
<td>88.00</td>
</tr>
<tr>
<td>Mean crystal size mm</td>
<td>0.38</td>
<td>0.43</td>
</tr>
<tr>
<td>Feed solution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass flow rate t/h</td>
<td>172.70</td>
<td>153.00</td>
</tr>
<tr>
<td>Purity %</td>
<td>99.00</td>
<td>99.00</td>
</tr>
<tr>
<td>Brix %</td>
<td>73.00</td>
<td>72.00</td>
</tr>
<tr>
<td>Heating steam pressure bar(a)</td>
<td>0.70</td>
<td>0.75</td>
</tr>
<tr>
<td>Vapour pressure bar(a)</td>
<td>0.20</td>
<td>0.25</td>
</tr>
<tr>
<td>Water evaporation t/h</td>
<td>34.30</td>
<td>32.00</td>
</tr>
<tr>
<td>Seed to massecuite %</td>
<td>27.10</td>
<td>34.50</td>
</tr>
</tbody>
</table>

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The VKT and batch pans at USC have an average evaporation rate of 12 kg/m² and 40 kg/m², respectively. Continuous pans in general have more surface area which compensates for this evaporation difference. The heating surface to volume ratio for both types of pan is shown in Table 1.
Retention time

The retention time of the volume flow in a stirred tank reactor can be calculated from the tank volume and the mass flows.

During recent measurements, the average crystal growth rate in the VKT was 125 microns per hour - starting at 0.43mm seed crystal size and full growth at 0.68 mm (Tables 6 and 7).

The total retention time of the VKT is 2.1 hrs for the above case.

Operating experience

The first few weeks of operations were very difficult from an operational point of view. Despite the initial satisfactory performance under vendor training and supervision, the operation gradually deteriorated.

The VKT was started with four cells in operation. The level control of cell 3 malfunctioned and was taken off-line and the pan operated on three chambers only.

The quality of the massecuite was extremely poor with wide crystal size distribution and a poor CV. This phenomenon was worse in the coarse crystal range with a large percentage of crystals retained on the 2000 micron sieve deck.

Samples taken from the VKT revealed excessive agglomerates and oversized crystals. Samples taken before the seed massecuite pumps revealed similar poor crystal size distribution. This was positive news because it confirmed that the VKT was not the cause of the agglomerates and oversized crystals. Attention was then paid to the seed preparation which is key for good massecuite crystal size variation.¹

Changes on parameters of the seed pan were carried out - constant vacuum, reduction of heating steam during seeding and minimizing the retention time at the slurry funnel - resulting in an improved crystal size distribution. However this still did not meet the USC specification.

Additional sampling carried out on slurry - diluted with fine liquor and microscopically analyzed - resulted in a similar crystal spectrum as found in chamber 4 massecuite, confirming that poor slurry was one of the major causes of the poor CV.

Other problems were also encountered:

1. The pan operators were finding it difficult to achieve the seed massecuite crystal size of 0.3 - 0.4 mm, producing 0.6 - 0.7 mm. The seed pan boiling program was changed from a step to a linear curve.
2. The slurry mill was producing poor quality slurry as seen under a microscope (Figure 6). This was due to worn ball-bearings.
3. The seed to massecuite ratio was often compromised due to seed shortage as the pan boilers were getting used to the new equipment. By reducing the output of the pan, the retention time and consequent crystal size increased.
4. The evaporation rate began declining after 7 days of operation as the encrustation increased resulting in large crystals and conglomerates.

Systematic corrective actions taken to improve the seed quality and quantity, resulted in an improved operation. Seed pan control parameters were changed by opting for constant vacuum, reduction of calandria steam pressure during seeding and minimizing the retention time at the slurry funnel. The worn ball-bearings in the slurry mill were replaced.

A second seed pan was made available to ensure a minimum seed to massecuite ratio of 25%. A new proactive approach was taken with regards to boil outs. (This is discussed under the section on fouling and encrustation.)

There were several noticeable changes in the behaviour of the refinery when the VKT was operating properly:

1. Steadier pressure on the exhaust steam range due to steadier consumption of steam compared to batch pans. The other contributor to this steadiness was the new large first effect evaporator which delivers the required V1 vapour.

![Figure 5. Comparison of slurry showing poor quality on the left](image-url)

**Table 8. Typical comparative crystal size analysis**

<table>
<thead>
<tr>
<th></th>
<th>Continuous pan</th>
<th>Batch pan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean aperture</td>
<td>0.65 - 0.70</td>
<td>0.52 - 0.60</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>32.40</td>
<td>35.60</td>
</tr>
<tr>
<td>Sugar less than 250 microns</td>
<td>2.20</td>
<td>9.50</td>
</tr>
</tbody>
</table>

Experience with continuous crystallization of refined sugar at United Sugar Jeddah

---

¹ Additional details on the seed preparation process and its impact on crystal size variation are included here for completeness. The updated seed preparation parameters and the rationale behind their changes are discussed in more detail in the supplementary technical notes. This ensures a comprehensive understanding of the operational challenges faced and the measures taken for improvement.
2. Steadier vacuum on the central vacuum system, due to a steady vapour generation from the VKT. Reduced vapour due to larger double effect evaporator configuration was also a factor. Simple and steady operations compared to the cyclical activity of batch pans.

3. Better massecuite quality which manifested itself by better purging with less wash water required.

Crystal size distribution

The quality of slurry, seed and the steady controlled conditions of the VKT and supporting systems has delivered a crystal quality which is satisfactory to USC and its customers. The quantity of false grain generated by the continuous pans is negligible compared to that produced by batch pans (Table 8).

The curve of the crystal size shape between the VKT and batch pans is distinctly different. The VKT produces consistently larger crystals and fewer smaller crystals.

The larger crystal size has a positive influence on the purging properties of the massecuite. The larger crystals offer larger interstitial spaces between crystals, allowing mother liquor free passage during centrifugation. The separation is easier.5

A sugar with larger crystals has a lower specific surface area (m²/kg).6 This smaller unit surface area makes the sugar easier to wash, so less water is required.

The crystal size distribution influences the purging properties of the massecuites because the crystals with a wide range of sizes, i.e. poor CV, will pack closely together during centrifugation and will hinder the free flow of mother liquor and wash water out of the basket.8

The VKT sugar crystal size variation is steady, while in the batch pan, every pan exhibits some variation in crystal size distribution and massecuite rheological behaviour, due to variation in brix and crystal content (Figures 6 and 7).

Sugar quality

In general, the sugar quality from the VKT was superior to the batch pan sugar, for all measured criteria.

Colour: Sugar colour from the VKT is better than from the batch pan at by about 15%. This is due to the higher MA and the lack of fines allowing for cleaner drainage of the mother liquor. Typically, with a fine liquor of colour

![Figure 6. Shape of crystal size in batch pans](image)

![Figure 7. Shape of crystal size in continuous vacuum pan](image)

![Figure 8. Drop in OHTC due to pan fouling](image)
95 ICU, the wet sugar colour of VKT and batch pan is about 6 ICU and 9 ICU, respectively - both using two seconds of wash water. The drying process increases the colour by 8 - 10 ICU.

**Moisture:** Centrifugal separation of the VKT massecuite is always cleaner and drier. The larger MA and comparative lack of tiny crystals ensured a drier final product.

Crystal size distribution: The VKT produces larger crystal size and less small crystal. The batch pan does the opposite. The slow evaporation rate and stable super saturation conditions ensure that the VKT produces less false grain.

**Fouling and encrustation**

In batch pans, steaming of the unit after every strike ensures that there is no residual sugar remaining on the walls, tubes etc. Continuous pans operate for long periods and are not subject to periodic discharge and steaming. Therefore encrustation in continuous pans is far more serious. Sucrose has a propensity to crystallize at high purity.7

The problem is a self-propagating chain reaction, where early encrustation causes a reduction of free circulation, leading to high pockets of supersaturated zones, resulting in the encrustation getting worse (Figure 8).

There are two well-known signs of the onset of encrustation in the USC vertical continuous pan. Firstly, there is a drop off in the evaporation rate and secondly, a deterioration of the cv, notably the appearance of a large crop of crystals above 2 mm in size.

Encrustation above the boiling surface is low because of the following reasons:

a. There are no sharp corners or edges for encrustation to take hold. The calandria is equipped with flush welded heating tubes resulting in a seamless flat tube plate.

b. Splashing is minimal due to the gentle boiling action as a result of the low temperature difference between heating steam and massecuite. The evaporation rate seldom exceeds 13 kg/m²°C compared with the batch pan where 60 kg/m²°C is quite common.

c. The syrup feed is administered above the massecuite on the inside walls of the pan using a ring distributor. The discharge holes on this ring faces the pan wall and feed runs down the wall keeping it wet and washed. This method of applying the feed washes down any potential wall based encrustation.

d. The stainless steel cladding is a thin plate welded at the edges. The stainless steel cladding is a thin plate welded.

e. Constant and steady calandria pressure.

Encrustation rates are higher in the last compartment where the brix is slightly higher and the crystal content is at its highest. The last chamber is boiled out twice a week to manage this phenomenon.

It is normal for continuous pans processing A massecuite at 85 - 90 purity to operate for 2 - 3 weeks, however at USC the VKT boiling at 99% purity, seven days is the norm.

The stainless steel cladding is a thin plate welded...
at the edges (Figure 9). This lining is able to flex and vibrate and encrustations do not appear to stick to it.

The syrup feed is administered above the massecuite on the inside walls of the pan using a ring distributor (Figure 10). The discharge holes on this ring faces the pan wall and feed runs down the wall keeping it wet and washed. This method of applying the feed washes down any potential wall based encrustation.

The proven standard operating procedure at USC is that all chambers are boiled out weekly, while chamber four is boiled once additionally during the middle of the same week. Before any cell is bypassed for water boiling, the other cells are ramped up by increasing calandria pressure and increasing the pan output so that there is no major production loss during the two hours the chamber is off line.

The vertical continuous pan design with multiple pans stacked in series, allows each chamber to be taken off line for water boiling. In order to reduce down time, hot water is first collected in a dedicated 60 m³ tank which is served with a pump capable of delivering 80 m³/h water. When a chamber is free of massecuite and ready for cleaning, water is pumped into it quickly within 15 minutes. After boiling for 60 minutes, the chamber is clean and the water is dropped back into the same tank. The contents of this tank are then slowly transferred to the sweet water. The outage time for any chamber on water boiling does not exceed 2.5 hours.

**Instrumentation and control**

The instrumentation found in continuous pans is very similar to that found in batch pans with some notable exceptions which will be discussed in this chapter.

There is however, one interesting difference between the vertical continuous pan, like the VKT, and a horizontal continuous pan like a THS CVP or FCB CVP. In a vertical pan the word ‘compartment’ has a different meaning. In horizontal CVPs, a compartment refers to a division in the massecuite holding chamber, while in a vertical pan a compartment is a totally isolated chamber which has its own calandria and vapour space.

The throughput of the pan is controlled by the calandria pressure of each chamber. The liquor feed flow depends on the evaporation rate (Figure 11). Consequently, the main control strategy involves the maintenance of a fixed ratio between seed and liquor feed. This means that the amount of sugar solids fed via syrup stays at the same ratio at any throughput capacity of the pan. The throughput capacity of the pan is controlled by the required evaporation rate which is controlled by calandria pressure control. Each cell can have a pre-set ratio so ramping the main pressure accelerator will not interfere in the ratio of calandria set for individual cells.

The absolute pressure of each compartment is controlled by a pressure transmitter and a 700 mm butterfly valve isolating the pan vapour space from the central vacuum header.

Brix control is provided by microwave probes which are provided with rinsing nozzles. These are timed to a pre-set interval of 7000 sec. and duration of wash water application of 8 sec. to remove encrustations. In batch pans these probes are cleaned between cycles when the batch pans receive a steam out. In the continuous pans there are no steam outs and the pan is expected to operate for many days between cleaning cycles.

Level control is provided by membrane type differential pressure transmitters which are also provided with suitable rinsing nozzles. A baffle plate installed in front of the level transmitter creates turbulence to rinse and remove encrustations within a pre-set time, without affecting the brix of the chamber.

Massecuite temperature is measured by PT100 temperature transmitters. Magnetic flow meters are employed for measuring condensate and feed liquor. The ratio of seed massecuite flow is controlled by inference using the shaft rotational speed in real time using VSD (Variable Speed Drive) At USC a vendor supplied a pan boiling program with the name “NAMAT” which has been implemented. This program controls the washing cycles, boiler pan, cleaning of chambers, seed and feed ratio semi automatically.

**Conclusion**

For refineries that require a moderate crystal size between 0.6 - 0.8mm or even bigger, the VKT has proven to be successful. The crystal size distribution is below 40 and when controlled properly can deliver a CV of 35.

The high purity issue of encrustation does not affect the capacity of the refinery due to the ability to bypass any of the four chambers for the short cleaning period.

The ability of the VKT to operate with a delta T of 30 degree Celsius allows the use of bled vapour, thus improving the over-all steam economy of the refinery.

The crystal deposition rate is slightly lower than the purchase specification and therefore the need for a slightly higher seed to massecuite ratio to deliver at full capacity.

**Acknowledgement**

The authors would like to acknowledge the support of the management of United Sugar for presenting this paper. Thanks also are due to Mr Eyad Nour for collecting some of the operational data and to Mr Faisal Wqadani for the numerous laboratory analyses.

**References**

Agricultural use of filter cake from the Tongaat Hulett sugar refinery†

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² Tongaat Hulett Sugar Refinery, Durban, Kwazulu-Natal, South Africa.

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abstract

Sugar refining is an energy intensive process which also generates significant quantities of waste and as such is under close scrutiny from environmental departments. In 2009, changes in waste legislation made recycling of waste a legal requirement, and responsible environmental management is therefore crucial (Anon, 2008). The obstacles facing the diversion of filter cake from landfill to agricultural use are discussed, as well as the strategy followed to obtain legal authorisation for using this waste in agriculture. The benefits of the material to the soil are discussed as well as the environmental benefits of diverting such a large tonnage of material from landfill which consumes valuable airspace.

Keywords: environmental, filter cake, lime, sugar refining, sustainability, waste minimisation

Introduction

Tongaat Hulett Sugar Refinery was established in 1910, with the purpose of refining raw sugar into white sugar. The refinery uses carbonatation as its clarification process. Powdered lime is used as the clarification agent.

The Refinery is located in an urban area, hence landfill disposal was originally the only option for solid waste. In 1998, the Department of Water Affairs and Forestry introduced new waste classification legislation (Anon, 1998). This resulted in the waste material being reclassified from general waste to a hazardous waste material, due to the manganese concentration. Manganese is inherent in the lime at present being used.

The waste was eventually delisted to general landfill; however, the cost had increased from R200,000 to R1 million within a year. This was a significant cost impact to the Refinery, which forced management to explore alternative uses for the material.

In 2009, Oricol Environmental Services and Tongaat Hulett Sugar Refinery began working together to find an alternative to landfill for the filter cake. The culmination of this process was authorisation from the environmental authorities to use the filter cake as a substitute for commercially available lime in agriculture and the subsequent distribution of the material to agricultural users.

Discussion

The filter cake generation process

The lime filter cake is produced as a by-product in the sugar refining process. Unslaked lime is delivered to the refinery and reacted with water to form milk of lime, \( \text{Ca(OH)}_2 \). The milk of lime is mixed with the melted raw sugar and then it is reacted with carbon dioxide to form calcium carbonate, \( \text{CaCO}_3 \). The calcium carbonate in turn assists in flocculating the fine contaminants of...
of these proved feasible. Filter cake has a moisture content of about 50%, which was the key reason why most of the options failed.

Voermol Feeds (the animal feed division of Tongaat Hulett Sugar) showed an interest in the material, as the calcium content would have been an ideal replacement for the lime that they purchase. Unfortunately, due to the high moisture content they would have had difficulty in processing the filter cake. Tongaat Hulett Sugar did investigate the option of drying out the filter cake; however, the capital investment that would have been required outweighed the savings that would be made and the cost of disposal of the material.

Agricultural project

Oricol Environmental Services approached Tongaat Hulett in 2009 with a view to implementing a project for diverting the material from landfill and using it as a lime replacement in the agricultural industry. Several tests were done with the South African Sugar Research Institute to assess the potential value of the material. It was found that the calcium levels were significant and that further investigation was warranted.

The next step in the process was to ensure environmental due diligence. This involved ensuring that there were no heavy metals present in the filter cake that would cause environmental problems or health hazards, or would have potentially adverse effects on the crops where the material was to be used. In the absence of other suitable standards to follow, the ‘Guidelines for the Utilization and Disposal of Sludge - Requirements for the Agricultural Use of Wastewater Sludge’, published by the Department of Water Affairs and Forestry, were studied, and the heavy metal limits for a ‘Class A’ sludge were used as limits to decide whether the material could be used in agricultural applications. It was found that the metals present in the filter cake were in the orders of magnitude lower than the limits laid down in the sludge guidelines and it was

### Table 1. Typical analysis of dried filter cake and powdered lime

<table>
<thead>
<tr>
<th>Component</th>
<th>Filter cake sample (% m/m on dried)</th>
<th>Powdered lime (% m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>0.12</td>
<td>1.20</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.20</td>
<td>0.50</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.20</td>
<td>0.40</td>
</tr>
<tr>
<td>MnO₂</td>
<td>0.46</td>
<td>1.10</td>
</tr>
<tr>
<td>MgO</td>
<td>1.57</td>
<td>2.10</td>
</tr>
<tr>
<td>CaO</td>
<td>46.2</td>
<td>90.70</td>
</tr>
<tr>
<td>CO₃</td>
<td>31.00</td>
<td>1.1</td>
</tr>
<tr>
<td>SO₄</td>
<td>2.10</td>
<td>0</td>
</tr>
<tr>
<td>Organics/water</td>
<td>18.35</td>
<td>2.00</td>
</tr>
</tbody>
</table>

### Table 2. Heavy metal results versus sludge guideline limits (Snyman and Herselman, 2006)

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Results Filter cake</th>
<th>Pollutant class (sludge type)</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium in µg/g</td>
<td>&lt;0.09</td>
<td>40 000-85 000</td>
<td>&gt;85 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Chromium in mg/L</td>
<td>13.67</td>
<td>1 200-3 000</td>
<td>&gt;3 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Copper in mg/L</td>
<td>3.01</td>
<td>1 500-4 3000</td>
<td>&gt;4 300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercury in µg/g</td>
<td>0.60</td>
<td>15 000-55 000</td>
<td>&gt;55 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molybdenum in µg/g</td>
<td>&lt;0.86</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Nickel in mg/L</td>
<td>11.74</td>
<td>420</td>
<td>&gt;420</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Lead in mg/L</td>
<td>11.06</td>
<td>300-840.00</td>
<td>&gt;840</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Zinc in mg/L</td>
<td>11.06</td>
<td>2 800-7 500</td>
<td>&gt;7 500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic in µg/g</td>
<td>&lt;0.40</td>
<td>40 000-75 000</td>
<td>&gt;75 000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The benefits of lime to soil are widely documented, and a summary of the main points are listed below (Dee et al., 2002; van Antwerpen et al., 2003):

- Optimising pH of the soil to improve nutrient availability and to improve root development into deeper soil layers.
- Improving the structure of the soil to increase water and nutrient holding capacity.
- It is a source of calcium especially for the vegetable industry.

**Authorisation**

Once enough market information had been gathered and the materials handling issues addressed, Oricol committed to taking the entire volume of lime and submitted a firm proposal to Tongaat Hulett Sugar Refinery which was accepted subject to final approval from the environmental authorities.

This proved to be a time consuming process as the project could not be ‘pigeon-holed’ in any of the environmental authorisation processes. At one stage, a letter was issued by the Department of Water Affairs and Forestry, stating that the project could proceed; however, a legal advisor had the opinion that this was not sufficient and Oricol had to go back to the drawing board.

A further technical motivation was compiled in conjunction with a legal opinion and submitted to the Department of Environmental Affairs stating the position that the material fell into the legal definition of a by-product and it should be allowed to be used in agriculture. Once this had been done a letter from the KwaZulu-Natal Department of Environmental Affairs was issued to qualify the material as a ‘by-product’, which meant that it would be exempt from the waste legislation requirements. The project then commenced.

Several conditions were laid down for the use of this material in agriculture due to the fact that historically this material was considered a waste and, as such, these projects are closely scrutinised by the Department of Environmental Affairs. Conditions stipulated included:

- The heavy metals in the lime had to be tested on a regular basis.
- Material could not be stockpiled anywhere for any extended length of time.
- Application rates per hectare had to be limited to the rates stipulated in the sludge guidelines.
- Volumes to various users had to be accurately recorded for environmental audit purposes.

In order to make this attractive to the farmers who were unsure of the value of material, the material was largely being given for ‘free’ to most, with a small handling and transport fee being charged to those in remote locations.

The project therefore did not have any significant commercial benefits to Tongaat Hulett Sugar. The benefits to the Sugar Refinery were:

- Improved environmental performance - diversion from landfill.
- Reduced reliance on local landfills in and around Durban. These sites are filling up and waste will have to be trucked.

**Field trials**

Oricol started removing a portion of the lime on a trial basis to ensure that the logistics and materials handling of the filter cake did not hold any surprises. One issue that was encountered was that, due to the tacky nature of the material, the lime would not release from the bin of the vehicle and would sometimes have to be manually removed, which caused delays in getting back to the refinery. This was resolved by having other vehicles and containers on standby to collect the lime should the vehicle be excessively delayed. This is a very important issue when transporting material to farmers in excess of 100 km away.

The second important issue was getting the material to spread evenly onto the fields. It was found that if the filter cake was turned a couple of times at the drop-off point, and left for a month or so, it dried to a crumbly material which could be applied reasonably effectively. There were still a lot of large lumps that had to be broken up and this could be done manually or mechanically. The application of the filter cake to fields is shown in Figure 1.

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- The heavy metals in the lime had to be tested on a regular basis.
- Material could not be stockpiled anywhere for any extended length of time.
- Application rates per hectare had to be limited to the rates stipulated in the sludge guidelines.
- Volumes to various users had to be accurately recorded for environmental audit purposes.

In order to make this attractive to the farmers who were unsure of the value of material, the material was largely being given for ‘free’ to most, with a small handling and transport fee being charged to those in remote locations.

The project therefore did not have any significant commercial benefits to Tongaat Hulett Sugar. The benefits to the Sugar Refinery were:

- Improved environmental performance - diversion from landfill.
- Reduced reliance on local landfills in and around Durban. These sites are filling up and waste will have to be trucked.
further afield within the next two to three years to landfill sites near Verulam at increased costs.

- Reduced risk of landfill price increases.

Current project status and way forward

The lime filter cake is currently being distributed mainly to farmers in the Howick and Mooi River areas. There are also a number of farmers up and down the coast that are taking smaller volumes, and it is hoped that this will grow in the near future. There is normally a fairly clear difference between farmers that will take the lime or not. There are those that are completely unwilling to try anything different and who do not want to be burdened with any additional materials handling ‘hassles’ and then there are farmers who will go to the extra effort to make use of the material due to cost savings.

Crop response

Having just started using the material for the first season there was little scientific information available to quantify the benefits of using the lime by-product vs. commercially available lime. However, most farmers have indicated pleasing results from applying the lime by-product. Soil samples were taken by some of the farmers and it is hoped that more information will become available after the season is complete.

Recognition

Tongaat Hulett Sugar Refinery participates in a biannual waste management audit and competition. This competition is managed by the Institute of Waste Management of Southern Africa (IWMSA), which is a multi-disciplinary non-profit association that is committed to supporting professional waste management practices. The organisation is comprised of voluntary members who promote environmentally acceptable, cost effective and appropriate waste management practices. At its biannual awards function, Tongaat Hulett Sugar did extremely well and won the following awards:

- Gold Award/Trophy for the first place in General Manufacturing based on achieving an audit score >90% on overall waste management systems and practices.
- Cleaner Production Trophy/Certificate - this award was in recognition of initiative related to conversion of filter cake (waste) from landfill for use in the agricultural industry as a fertiliser

Conclusion

The agricultural use of both sugar milling and refining filter cakes in agriculture is a well established process in the sugar industry (Tzeng et al., 2001). However, due to circumstances faced by Tongaat Hulett Sugar Refinery, this option did not seem viable for numerous years. Changes to legislation, together with a passion and commitment towards achieving sustainable environmental practices, have resulted in successful re-use of the filter cake in agriculture.

References


1. Introduction

Once the beet sugar juice is concentrated in the evaporator stages, this thick juice reaches the sugar house where it is crystallized into sugar crystals. The main activities carried out in the sugar house are the crystallization of the dissolved sucrose and the separation of the sugar grains from the remains of the syrup.

The production scheme of the crystallization plant is notably elaborated, with several processing stages, each one with different technological requirements (Poel et al., 1998). The crystallization of sugar, in spite of important advances, is still very far from being fully automated. The instrumentation is, in many cases, still inadequate. Important quality indexes like those related to the characteristics of the population of grains, or the purity of the circulating products, are only measured off-line in the laboratory of the factory. Variables like supersaturation, which are critical to the process, should be inferred from others, whose on-line measurement is, in its turn, also problematic.

This situation demands the knowledgeable intervention of the operators. The expertise which is required, all the more difficult to achieve due to the seasonal character of the industry, implies not only the attention to the functioning of the individual units, but also the smooth working of the whole plant, taking into account the long range interactions which are evident in a process with several hours response time and with many recycling loops.

In this context, the help provided by a continuous time realistic dynamic simulator for the training of operators, cannot be disputed. This paper explains some of the more important details concerning the modelling assumptions (section 3) and the characteristics of such a tool (section 4), representing a scaled down version of a Sugar House with the same structure (section 2) as an existing factory in Spain. Two related articles on this topic have already been published. The first describes the general architecture of the training software (Acebes et al. 2011) and the second is concerned with the discussion of the beet house part of the simulator (Merino et al. 2012).

2. The three stage sugar house scheme

The department modelled follows a variant of the standard three stage production scheme (see Figure 1). The first “A” stage is concerned with the production of the commercial white sugar and the two downstream passes in series, labelled “B” and “C”, are dedicated to the exhaustion of the remnant syrup. Each stage is composed of the same processes of crystallization and separation by means of filtering centrifuges; although the technological working conditions and requirements are different.

The crystallizers and centrifuges on the “A” stage are typically of a batch character because the interest here lies in guaranteeing the quality of the marketable product: the uniformity of the grain and its purity. Crystallization is mostly conducted in semi-batch crystallizers (Feyo de Azevedo et al., 1994; Mazaeda and Prada, 2007) where the rhythm of water evaporation and the supply of feed liquor are carefully combined to keep the supersaturation of sucrose in the solution at moderate values, well within the so called metastable zone.
An array of batch centrifuges receives the massecuite elaborated in the pans, and uses the increased separation factor produced by their rotating drums to get rid of the mother liquid. The high purity demanded by the white sugar product requires the introduction of water at some instant of the cycle to eliminate, by diffusion, as much syrup as possible from the pores of the sugar crystal cake, at the cost of dissolving some of the already crystallized sucrose. A too spread crystal size distribution (CSD) would mean a less permeable more compact bed (Bruhns, 2004), and thus the need to handle more viscous masses and this is why, starting in the “B” stage, but fundamentally in the final “C” stage, the use of a continuous type of unit, where operation is conducted smoothly around a slowly varying nominal point, are preferred.

The last stage uses, almost exclusively, continuous crystallizers and centrifuges. There is initially a batch pan for creating a seed magma containing the crystals that are to be grown in the downstream continuous crystallizers, which are, in sequence, an FCB type vacuum evaporative unit (Journet, 2002; Hassani et al., 2002) and a series of four vertical crystallization towers where the supersaturation is created by cooling. The “C” massecuite emerging from the FCB unit is already highly viscous and the fact that its temperature is going to be reduced in its transit through the towers means that a further increase is sure to happen. As a partial remedy to this problem, part of the “C” mass is deviated to the so called intermediate centrifuges. The sugar obtained here should be recycled back, but the separated syrup is mixed with the main stream of massecuite, thus reducing the effective viscosity of the slurry at the input of the first tower. The mass at the output of the towers is passed by the “C” continuous centrifuges. The separated molasses are a by-product of the factory, still useful for alcohol production and the third stage recovered sucrose is obtained in the form of crystals.

However, the intermediate and “C” sugars should not be directly recycled to the first stage, the reason being that the composition of their adhered impurities is not appropriate because of the presence of colouring substances which were highly intensified in this stage due to the long processing times. The third stage sugars should then first undergo a process of affination, where they are mixed with “B” syrups of a much lighter colour. Afterwards, the resulting homogenized affination mass is fed to dedicated continuous centrifuges and the emerging crystals are finally good enough to be used in the conformation of “A” standard liquor.

The purpose of the “B” and “C” stages is to recover as much sucrose as possible. The sugar crystals obtained in these stages, without direct commercial value, are ultimately recycled to conform the “A” standard liquor. The recovered sugar quality is not an important issue, although the uniformity is not to be neglected for the above mentioned centrifuging requirements. On the other hand, sugar purity should not be too low to avoid the risk of decreasing the quality, and particularly the colour, of the feed syrup of the commercial pass.

It is known that a decrease in purity affects the crystallization process. A greater concentration of impurities determines an increase of the solubility of sucrose in the technical solution, meaning a greater effort for creating the required supersaturation: more evaporation of water, for example. Then, a lower purity means the need to handle more viscous masses and this is why, starting in the “B” stage, but fundamentally in the final “C” stage, the use of a continuous type of unit, where operation is conducted smoothly around a slowly varying nominal point, are preferred.

An array of batch centrifuges receives the massecuite elaborated in the pans, and uses the increased separation factor produced by their rotating drums to get rid of the mother liquor. The high purity demanded by the white sugar product requires the introduction of water at some instant of the cycle to eliminate, by diffusion, as much syrup as possible from the pores of the sugar crystal cake, at the cost of dissolving some of the already crystallized sucrose. A too spread crystal size distribution (CSD) would mean a less permeable more compact bed (Bruhns, 2004), and thus the need to increase the amount of water with the associated negative impact on the efficiency of the factory. As a result of washing, typical batch centrifuges deliver two types of syrup separated by time: first, the poor or green run-off syrup corresponding essentially to the original mother liquor, and then a higher purity rich or wash run-off syrup receiving most
3. Modelling approach

The underlying continuous time dynamic model, used in the simulator, has been created using components taken from an Object Oriented (OO) generic library representing the main units of a sugar factory (Mazaeda, 2010; Merino, 2008).

All the components have been built from first principles, following a consistent approach which has been consciously tuned to operator training. All the mass, energy and crystal size distribution population balances have been meticulously laid out. This has to be so, since the general character of the library prevents the possibility of anticipating which specific variable the designer of a still to be constructed simulator would be interested in showing to trainees.

The dynamics of the process models are mainly determined by the rate processes, such as those representing the kinetics of heat or mass transfer, the latter being basic in a plant where the main activities are the crystallization and dissolution of sugar crystals. The approach followed has been the estimation of this kind of rate coefficients by semi-empirical correlations between the appropriate non dimensional numbers adapted to the specific situation. Crystallization has been put in relation with many other variables, including the purity of the syrup, its temperature, viscosity, density and degree of agitation through an expression due to Ekelhof and Schliephake (1995).

A key factor in the quality of models is attributable to the accuracy of the properties of the technical streams considered. Here, the data compiled in Bubnik et al. (1995) have been used.

4. Simulator characteristics

A Sugar House simulation that reproduces the department described in section 2 has been created. In what follows, a description of some of the more important characteristics of the tool are commented on, with special emphasis in the training opportunities offered.

A trainee would interact with a human-machine interface (HMI) that should be very similar to the one encountered in the real situation. The root screen of the Sugar House part of the simulation is presented in Figure 2. The layout evokes the structure of the section and places the access to the more detailed information of any specific unit or to the simulated laboratory reports just one mouse click away.

4.1. First stage

Each of the batch vacuum crystallizers are monitored from an HMI screen as shown in Figure 3. The underlying model accurately represents the control solutions adopted in the factory and the details concerning the program that drives the step by step evolution of the pan.

The recipe followed by the semi-batch crystallizer includes the loading of the feed liquor, its concentration to reach a supersaturation in the metastable zone, the seeding of the initial mass of crystals, the growing of the implanted grain, a tightening up phase to increase consistency, the discharge of the mass and...
a final steam cleaning step to remove traces of massecuite and prepare the pan for the next cycle.

The seed step could be executed manually or in automatic mode. The manual seed mass should be prepared and placed on the corresponding tray by the operator upon the reception of a visual warning issued by the controlling program. Otherwise, it is possible to perform the seeding by means of the automatic introduction of magma of a higher average size, which is the result of a previous partial crystallization carried out in a separate unit.

The growing phase is controlled by striking the right combination between the evaporation rate and the introduction of feed liquor. The rhythm of evaporation is decided by the setpoints of the controllers of the pressure in the calandria and of the vacuum level in the chamber. The rate of standard liquor to the pan must be chosen so as to keep the supersaturation, a not directly measured variable, in the metastable zone. The scheme adopted in the modelled installation is to use the readings of a radio-frequency probe, which can be put in relation with the Brix of the massecuite, to conduct crystallization. But the Brix that should be enforced at each moment changes with the conditions of the mass and of the feed syrup. The solution implemented by the pan controlling program is to establish a curve of concentration values used to provide the setpoint to the underlying PID loop that, according to the operator judgment, would result in the right supersaturation at the current point in the crystallization process evolution. The level reached by the slurry inside the pan is the available measurement that can be readily put in relation with the mentioned strike progress. Obviously, the resulting Brix versus level curve should be frequently tuned by the operator according to the current purity of the standard liquor obtained from the most recent laboratory report.

The simulation allows the operator to track the exact stage that is currently active, and the current value and time evolution of some variables. In Figure 5, the user observes the profile of the drum velocities over several cycles. The operator should react to changes in simulation conditions by modifying the right parameters. A decrease of the permeability of the cake, for example, could be countered by an increase in the duration of the washing phases; although he/she should be aware that the long term solution resides in a better crystallization work. Another important parameter to tune is the one that specifies the exact instant, counted in seconds from the start of the first washing, when the expelled filtrate should be redirected from the poor to the rich syrup pipe circuit. A careless consideration of this switching time could mean a decrease in the purity of the recycled rich syrup,
with a negative impact on the quality of commercial sugar or an undue increase in the same index with regard to the poor syrup, which is bad for efficiency, since too much sucrose would be sent to the exhausting stages (Mazaeda and Prada, 2010).

As already explained, technological decisions should be based on the data elaborated in the factory laboratory. Figure 6 shows how laboratory results are reported to the users by the simulator interface.

4.2. Second and third stages

Figure 7 represents the root screen corresponding to the simulated factory second stage and the affination process. At a glance, it provides, for example, the current state of each of the two batch evaporative crystallizers and the level attained in the stage strike receivers and “B” feed liquor formation tanks. The more specific interfaces concerning the individual units: the crystallizers or the continuous centrifuges are readily accessible.

The HMI screen in figure 8 provides important “C” stage information in a compact way and at the same time acts as a dispatching hub to reach those interfaces directly dealing with any of the main installations deployed as part of the sub-section.

The interface for working with the continuous vacuum evaporative pan, for example, allows for the individual modification of any of the many existing control loops (see Figure 9). The correct conduction of the crystallizers demands the establishing of a curve of Brixes, conceptually similar to the one explained for the batch crystallizer, but in this case deployed in the spatial dimension, from one compartment of the unit to the next. This curve of concentrations, which would of course be dependent on the “C” feed liquor purity, would be enforced by the mass flow rate of seed magma and its characteristics, such as its crystal content, by the evaporation rate, and by the amount of syrup introduced at each of the existing five inputs, strategically situated along the pan, which are responsible for replenishing the dissolved sucrose that progressively migrates to the faces of the growing crystals (Mazaeda et al., 2011). The steady state regime of operation should be such as to guarantee the complete consumption of all the syrup arriving from upstream, taking into account, additionally, the need to divert some of the latter for the production of seed magma in the corresponding batch unit.

4.3. Overall management

The technical personnel in charge of the department should not only be concerned with the operation of the individual installations, but they must also be aware of the multiple ways the different units interact. The final objective is, of course, to achieve the quality standards for the main product, minimizing the purity in molasses and the use of steam energy. However, in order to accomplish the above, the operators should make the plant work smoothly, foreseeing possible bottlenecks and
preparing for the necessary adjustments with enough time to avoid abrupt changes.

The requirement of a consistent way of working beyond the individual units has already been mentioned in relation with the impact of the crystallization work on the correct performance of the downstream centrifuges. But this relation goes both ways: if, due to bad sugar cake permeability, the amount of water to the centrifuges were to be increased, the resulting purer and less concentrated syrups would end up affecting the crystallizers operation at every stage of this highly interacting plant.

The need for coordination is also evident, for example, to guarantee inventory control of the syrup in the feed liquor tanks and of the massecuite in the strike receivers, manipulating the scheduling of the batch crystallizers and the processing throughput of the array of centrifuges. The problem is not a simple one because it involves the intermittent working of the vacuum pans with long processing times, which are, in turn, highly dependent on the purity and concentrations of the involved streams.

Furthermore, the Sugar House plant is not to be seen in isolation. The characteristics of the incoming thick juice, are of course important. A higher purity could demand from the technical managers, the premeditated lowering of the “B” stage feed syrup purity by recycling a part of the same stage’s poor syrup, a feat that can be done from the HMI screen shown in figure 7. The reason for this lies at the root of the use of this intermediate stage as a kind of buffer to compensate for the changes in the purity of the syrup entering the sugar house (Asadi, 2007). An increase of thick juice purity, a circumstance which would, in principle, be beneficial to the working of the first stage processing, would appear finally as a prejudicial increase in the purities of the molasses. This effect is due to the fact that the purity jump achieved at every stage does not change very much, all other factors being equal.

The department is a heavy consumer of steam which is provided by the evaporation section of the upstream Beet House. The operators should be conscious of the fact that they are dealing here with a valuable, scarce resource. In batch crystallizers, there exists the possibility of changing the source of the heating steam from the fourth evaporator effect to the third as the cycle progresses. The lower pressure fourth effect steam could be used in the non syrup consuming steps, like concentration; while the third effect steam should possibly be considered for the last steps, when steam consumption falls, due to a very diminished heat transfer coefficient.

In any case, as the Sugar House is not the only steam consumer of the factory, the availability of the resource could change without notice and the operators should be able to cope in that restricted context: making the necessary adjustments for complying with quality standards, consuming all the incoming syrup, while minimizing losses.
4.4. Role of the instructor

The training of the operators in the control of the simulated individual units with their manifold interrelations is, as hopefully conveyed by the preceding discussion, enough of a challenge in itself. In any case, the Sugar Factory Simulator makes provision for the figure of the instructor, with special privileges for modifying some parameters of the model and so introducing a premeditated alteration in the simulated plant regime. The idea is to challenge the trainee with the new operative situations in order to evaluate his/her reaction in adapting to them, gathering information exclusively from the existing simulated instrumentation and using only the regular range of possible actuations at his/her disposal.

The meaningful possible instructor interventions are numerous, to mention just a few: the behind the scenes alteration of the program parameters for any of the batch units; the introduction of a bias in the readings of some instrument; the artificial modification of the properties of the mass at some specific point, as for example, changing the proportion of false grain that goes to a centrifuge; and finally, tampering with some physically significant model parameters, as would be the case of the reduction of heat transfer coefficients of the batch pan calandrias or other heat exchanger units.

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References


Reducing colour helps reducing sugar loss in refinery: Process problems and adapted solutions†

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abstract

This paper reviews the use of patent pending high performance adsorbents CarboUA products in sugar refineries in order to achieve enhanced daily production, process efficiency, improved filterability for carbonatation refineries and savings on energy cost. Different processes and technologies for sugar purification and their impact on sugar recovery will be reviewed and discussed. How CarboUA products enhanced carbonatation and phosphatation clarification, as well as its further application with 2-stage purification methods for a possible by-pass of the unit operations such as granular activated carbon or ion-exchange resin will be reported. The benefits will be presented based on (1) improved final liquor colours and better refined quality (2) improved daily throughput of sugar solids (3) improved conversion rates of refined sugar per ton of raw sugar melt (4) reduction in the amount of recycled (double-processed) recovery sugar and (5) reduction in energy consumption per ton of sugar produced. The paper also includes graphical reports and schematic diagrams showing point of product addition and general refinery flow with reference to practical application of the CarboUA products in several sugar refineries around the world.

Keywords: adsorbents, CarboUA, decolourization, sugar refining

Redução de cores ajuda a reduzir as perdas de açúcar na Refinaria de açúcar: Problemas de processo e soluções adequadas

Este trabalho revisa o uso dos adsorventes de alto desempenho da CarboUA em refinarias de açúcar, a fim de atingir um aumento na produção diária, maior eficiência do processo, melhoramento da filtrabilidade para refinarias de carbonatação e redução de custos em termos de energia. Diferentes processos e tecnologias para purificação de açúcar e seu impacto sobre a recuperação do açúcar serão revistos e discutidos. Será apresentada a forma como os produtos CarboUA melhoram os processos de carbonatação e fosfatação, assim como a aplicação dos produtos em duas etapas para um possível “by-pass” de operações unitárias, tais como GAC ou Resina de troca iônica. Os benefícios serão apresentados baseados em (1) melhores cores de licor final e melhor qualidade de açúcar refinado (2) maior produção diária de sólidos de açúcar (3) melhores taxas de conversão de açúcar refinado por tonelada de açúcar bruto fundido (4) redução na quantidade de reprocessamento (duplo-processamento) de açúcar recuperado e (5) redução no consumo de energia por tonelada de açúcar produzido. O documento também inclui relatórios gráficos e diagramas esquemáticos que mostram os pontos de adição dos produtos e os diagramas de fluxo de refinaria com referência à aplicação prática dos produtos CarboUA em refinarias de açúcar em diferentes partes do mundo.

Reduzir coloração ajuda a reduzir a perda de açúcar na refinaria: Problemas de processamento e soluções adaptadas

Este paper analisa o uso da patente pendente de produtos de adsorventes de alto desempenho da CarboUA em refinarias de açúcar para atingir maior produção diária, eficiência do processo, melhor filtrabilidade para refinarias de carbonatação e economia em custos de energia. Diferentes processos e tecnologias para a purificação do açúcar e seu impacto na recuperação de açúcar serão revistos e discutidos. Como produtos CarboUA aprimorados de clareamento de carbonatação e fosfatação, bem como sua aplicação como métodos de purificação de 2 estágios para uma derivação possível de operações unitárias, como carvão ativado granulado ou resina de troca iônica será relatado. Os benefícios serão apresentados com base nas (1) uma melhor color do licor final e melhor qualidade de refino (2) melhor qualidade de sólidos de açúcar (3) melhores taxas de conversão de açúcar refinado por tonelada de açúcar bruto (4) redução na quantidade de açúcar reciclados (duplicamente processados) (5) a redução no consumo de energia por tonelada de açúcar produzido. O estudo também inclui relatórios gráficos e diagramas esquemáticos mostrando o ponto de adição de produto e fluxo de refinaria geral com referência à aplicação prática dos produtos CarboUA em várias refinarias ao redor do mundo.

Introduction

This paper presents a review and comparison of different types of clarification and decolourisation processes, including the use of high-performance adsorbents technology newly developed by CarboUA that have demonstrated to be an excellent alternative in terms of cost-benefit assessment. Additional to the process comparison some case studies regarding how specific problems have been solved are also presented.

Production of high quality refined sugar, maximizing process efficiency and minimizing energy consumption, are the prime objectives of all sugar refineries in order to optimize profit margin and returns to stakeholders. Current process for clarification and decolourisation offer the opportunity to process raw sugar so that the final liquor after purification has the necessary quality for a good exhaustion (recovery of sucrose in crystals), thereby fulfilling the quality parameters required in the industry.

Choosing the right kind of clarification process and/or decolourisation requires a careful evaluation of the pros and cons of each alternative technology available in the market. Final
Decision depends on the alternative that best meets the needs of each particular process. Selection of the correct purification process and strategy is very important not only because it will obviously determine the final quality of the processed sugar but also will be a critical factor in determining refinery yield. Several authors have made fair comparisons between the different purification technologies, especially in terms of efficiency of purification, colour removal, etc. However, only a few studies have so far been carried out to analyze the cost-benefit of each technology, considering purification efficiency, operational cost and effect on the refinery yield.

Table 1. is a modified version of the table appearing in Rein’s book (2007) that compares colour removal technologies. With the advent of CarboUA’s new patent pending high performance adsorbents, the authors were compelled to include this in the table.

It is clear by analyzing the table above that there are purification processes, such as High Performance Adsorbents, that are more adaptable to meet an assorted needs, with a better cost-process ratio and better flexibility to different process conditions.

The reason why CarboUA’s High Performance Adsorbents are effective in solving different problems and bottle necks in sugar refineries is because they combine the main principles and active ingredients of other clarification and decolourisation processes.
Combining the main strengths of the existing clarification and decolourisation processes it is possible to create a “single process/product” with ability to remove more impurities and generate proper conditions for an enhanced plant yield.

Next, some process problems and adapted solutions are presented through cases studies:

**Case study n°. 1 (Sarir et al. (2011))**

**Process bottleneck**

A 900 t/d sugar refinery in Colombia operating a backend refinery to a cane sugar mill based on the phosphatation process. The refinery processes melt liquor with a colour of 400 to 500 IU. Before the use of CarboUA’s products at this mill, the fine liquor had a colour of 200 to 250 IU after the phosphatation clarifier. The plant operated a back-boiling crystallization scheme with liquor to syrup ratio of 60 to 40.

**Proposed solution by CarboUA**

The aim of the project was to increase plant throughput by decreasing colour and turbidity in the phosphatation clarifier. This would support the production of high quality sugar in order to meet customer specifications, particularly bottlers who have stricter standards.

**How the problem was solved**

250 mg/kg of CarboUA’s high performance adsorbent was added to the raw sugar being melted. This lowered the syrup colour after the pressure filter to 100 to 150 IU. As a result the ratio of liquor to syrup for the back boiling crystallization system was modified to 50:50. The low colour in the syrup allowed better massecuite exhaustion and lower run-off recirculation within the refinery process. This increased the throughput tremendously, produced sugar of better quality and saved considerably in energy usage.

**Discussion of results**

Table 3 highlights the findings from adding the adsorbent. Compared with conventional phosphatation, the colour removal was improved by 21% through the use of CarboUA’s adsorbent.

It is apparent from Table 4 that the addition of 200 mg/kg high performance adsorbent reduced phosphoric acid dosing rate by over 15%, flocculant by 30%, polymer decolourant by 53% and filtration aid by 25%. It also led to the elimination of powdered activated carbon that was used during the decolourisation stage after phosphatation.

The improvement in the final liquor quality led to a reduction in the amount of wash syrup in the centrifugals, which resulted in less run-off syrup (Energy saving). By increasing the liquor to run off syrup ratio to 50:50 it was possible to reduce the amount of syrups returned back to raw house by 42% (increased yield and quality) (Pabon et al. (2003))

Figure 1. shows the number of 50:50 strikes after addition of the adsorbent.

The daily refined sugar production increased by 6% after the addition of the adsorbent.

**Case study n°. 2 (Bogari et al. (2008))**

**Process bottleneck**

This involves a carbonatation sugar refinery in the Middle East with a production capacity of 3000 t/d. It processes raw sugar of 900 - 1300 IU. The carbonatation is followed by a filtration step and granular activated carbon for colour removal.

The existing process parameters are:
- Flow rate of 235 m³/h
- Syrup with a Brix of 55% to 58%
- Syrup colour after filtration of 750 IU
- Refined sugar output of 3300 t/d

**Proposed solutions by CarboUA**

The aim of the project was to increase sugar throughput by increasing Brix of the syrups and/or the process flow rate. By improving the carbonatation performance a lower final liquor colour should be obtained, thereby enhancing white sugar production with constant or higher quality. Here the high performance adsorbent was added to the maturation tank after carbonatation, but before filtration.

**Table 3. Colour removal comparison**

<table>
<thead>
<tr>
<th>Process method</th>
<th>Melted liquor</th>
<th>Final liquor</th>
<th>% removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphatation only</td>
<td>363</td>
<td>203</td>
<td>44</td>
</tr>
<tr>
<td>Enhanced phosphatation</td>
<td>408</td>
<td>143</td>
<td>65</td>
</tr>
</tbody>
</table>

**Table 4. Phosphatation chemical reduction**

<table>
<thead>
<tr>
<th>Process method</th>
<th>Phosphoric acid</th>
<th>Flocculant</th>
<th>Decolorant</th>
<th>Filter aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal phosphatation</td>
<td>578</td>
<td>10</td>
<td>153</td>
<td>1561</td>
</tr>
<tr>
<td>Enhanced phosphatation</td>
<td>488</td>
<td>7</td>
<td>71</td>
<td>1161</td>
</tr>
<tr>
<td>% reduction</td>
<td>15.6</td>
<td>30</td>
<td>54</td>
<td>25.6</td>
</tr>
</tbody>
</table>
How the problem was solved

The process parameters of the enhanced carbonatation using CarboUA’s adsorbent were as follows:
- Flow rate of 260 m$^3$/h (+9.6%)
- 61% Brix in the syrup
- Colour of the syrup after filtration of 525 IU
- Refined sugar output of 3700 t/d.

The improved adsorption of non-sugars like starch and dextran allowed for a better filtration rate.

Table 5 shows the reduction of colour in the fine liquor after the granular activated colour (GAC) due to the addition of the CarboUA adsorbent.

The factory was able to reduce the centrifugal wash time to 2/1 seconds on the 1st strike, compared to 3/2 seconds with the normal carbonatation process.

Maximizing daily production capacity within the constraints of existing sugar house capacity allowed a 12% increase in the daily production of refined sugar (Table 5).

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The use of CarboUA’s adsorbent positively impacted on all the process parameters (Table 6).

A 19% reduction in fuel oil consumption, a 25% reduction in steam consumption, and 29% reduction in water consumption were achieved (Table 7) as a result of positive impact on process parameters through enhanced carbonatation.

Case study no. 3

Process bottleneck

This refers to a stand-alone phosphatation refinery in Africa, which processes more than 3000t raw sugar/day with colour of 600 - 700. After clarification, syrup is decoloured through an ion exchange unit, resulting in a final liquor colour of 220 to 280 IU. The refinery uses a straight crystallization scheme, whereby the first three sugars R1, R2and R3 are blended and packed. Before the project the R4 sugar colour was too high to be mixed into the product for sale. Therefore the R3 stage back-boiling system was used.

Table 5. Final liquor colour reduction and increase in RSO

<table>
<thead>
<tr>
<th>Process method</th>
<th>Fine liquor Colour (after GAC)</th>
<th>Daily INCREASE Refined sugar output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatation only</td>
<td>225-250 IU</td>
<td>-</td>
</tr>
<tr>
<td>Enhanced carbonatation</td>
<td>125-150 IU</td>
<td>12% increase</td>
</tr>
</tbody>
</table>

Table 6. Process comparison: Carbonatation only vs. enhanced carbonatation

<table>
<thead>
<tr>
<th>Process method</th>
<th>Process flow rate (m$^3$/hr)</th>
<th>Liquor concentration (°Brix)</th>
<th>Filtered liquor Colour (IU)</th>
<th>Average RSO (Tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatation only</td>
<td>235</td>
<td>55</td>
<td>775</td>
<td>3300</td>
</tr>
<tr>
<td>Enhanced carbonatation</td>
<td>260</td>
<td>61</td>
<td>525</td>
<td>3700</td>
</tr>
</tbody>
</table>

Table 7. Process comparison: Energy savings

<table>
<thead>
<tr>
<th>Process method</th>
<th>Fuel oil (kg/ton RSO)</th>
<th>Steam (Tons/ton RSO)</th>
<th>Water (kg/ton RSO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatation only</td>
<td>84</td>
<td>1.13</td>
<td>620</td>
</tr>
<tr>
<td>Enhanced carbonatation</td>
<td>68</td>
<td>0.84</td>
<td>440</td>
</tr>
</tbody>
</table>

Table 8. Refined sugar colour profile

<table>
<thead>
<tr>
<th>Process method</th>
<th>Fine liquor colour (IU)</th>
<th>R1-R4 Sugar colours (IU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphatation followed by IER</td>
<td>220-280 IU</td>
<td>R1: 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3: 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R4: N/A</td>
</tr>
<tr>
<td>Phosphatation WITH adsorbent</td>
<td>120-180 IU</td>
<td>R1: 12</td>
</tr>
<tr>
<td>followed by IER</td>
<td></td>
<td>R2: 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3: 38</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R4: 75</td>
</tr>
</tbody>
</table>

Table 9. Phosphatation chemical reduction in a refinery in Africa

<table>
<thead>
<tr>
<th>Process method</th>
<th>Polymer decolourant (ppm)</th>
<th>Phosphoric acid (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphatation only</td>
<td>330 ppm</td>
<td>450 ppm</td>
</tr>
<tr>
<td>Phosphatation WITH adsorbent</td>
<td>125 ppm</td>
<td>250 ppm</td>
</tr>
</tbody>
</table>

Case study no. 4

Process bottleneck

This involves a carbonatation sugar refinery in South Asia.
Table 10. Process comparison: Carbonation only vs enhanced carbonatation in SEA

<table>
<thead>
<tr>
<th>Process method</th>
<th>High colour sugar/VHP mix ratio (%)</th>
<th>Process flow rate (m³/hr)</th>
<th>Filter cycle (Hours)</th>
<th>Filtered liquor colour (IU)</th>
<th>Colour removal melted vs filtered (%)</th>
<th>Refined sugar output (Ton/day)</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonation only</td>
<td>5</td>
<td>45</td>
<td>5 - 6</td>
<td>830</td>
<td>50 -</td>
<td>688</td>
<td>-</td>
</tr>
<tr>
<td>Enhanced carbonatation</td>
<td>20-30</td>
<td>50</td>
<td>Up to 7</td>
<td>670</td>
<td>72 - 22%</td>
<td>785</td>
<td>14%</td>
</tr>
</tbody>
</table>

General conclusions

The use of CarboUA’s high performance process aids have shown to significantly enhance Carbonatation clarification operations in refinery via improvements in process throughput, brix increases and increased decolourisation.

These benefits have resulted in an increase in daily refined sugar output (RSO) even with the constraints of existing process equipment, as well as reduction in energy consumption per ton RSO.

Similar observations have also been noted in refineries employing phostphatation clarification process.

Further, the process aids can be utilized in a secondary clarification step (either after phosphatation or after carbonatation) to impart additional decolourisation and improved sugar throughput at dosages much lower than conventional powder carbon.

In all the cases mentioned above it is demonstrated that production rate has increased by 5 to 12% for the same energy input. Detail analysis has confirmed significant cost benefit for each sugar refinery when they use of CarboUA’s adsorbents.

Problem solved

The use of CarboUA’s adsorbents resulted in the following improvements at the sugar refinery:

1. Flow rate was maintained at 50 m³/h (about 11% increase)
2. Filtration cycle was improved from average of 5-6 hours to up to 7 hours (improvements by 15-20%).
3. The colour removal by the enhanced carbonatation process was improved to about 72%, with raw melt liquor at 1650 IU and filtered liquor at 825 IU.
4. Refined sugar output increased by nearly 100 tons to 785 tons/day.

Table 10. highlights the effectiveness of CarboUA’s adsorbents across the refining process.

The use of CarboUA’s adsorbents resulted in optimizing the mixing rate of high colour sugar with VHP raw sugar, this effectively facilitated the processing of 15,000 tons High Colour Raw Sugar within about 4 months with 20-30% mixing rate, compared with more than 1 year with only 5% mixing.
Introduction

A new design-engineering approach has to be taken if, in the light of ever increasing demands, an already highly sophisticated product is to be further optimised. This is where technical excellence, i.e. the ability to find straightforward solutions to highly complex processes, comes to bear. In developing this generation of centrifugals, the machine's mechanics were consistently reduced to the bare minimum, movements were simplified, and maintenance-intensive components were eliminated. With its E-series centrifugal, BMA is again setting new standards.

Efficiency is the measure of successful development. The efficiency level that has been achieved in the new E-series centrifugal generation is primarily due to shorter cycle times, which increases the throughput per hour. A key element to reducing cycle times is the discharger. Since it does without a vertical motion axis, the discharging time is reduced by up to 20% (see Figure 1). Once the discharging speed has been reached, the discharger only swings horizontally into the sugar layer and removes the sugar along the entire height of the basket at one go. The vertical motion axis could be eliminated because the

Discharging at one go

...
E centrifugal basket comes with a novel hub geometry, which also provides an enhanced torsional rigidity in comparison with the earlier hub version. Although the basket volume has been increased, too, the E machine can handle at least one additional batch per hour - with the same drive that is used in the earlier centrifugal series.

Innovative syrup separation

One of the fundamental process-specific innovations is the syrup separation flume that provides for excellent separation into high-green and green syrup without any internal mechanical elements. The primary aim consists of precisely separating the mother liquor and the dissolved sugar obtained during the water washing phase and during the screen washing phase after the basket has been emptied. The advantages for the sugar-end processes are a higher sugar yield and reduced recirculation of non-sugars. In the final analysis, this also permits producing molasses of a lower purity.

The challenge with syrup separation is to prevent the separated mother liquor from mixing with the wash syrup in order to produce a sufficient amount of very high purity syrup.

The new BMA syrup separation flume solves this task in an excellent manner - both with an optimised shape of the housing bottom and the way that the discharge nozzles are operated, which is done from the outside of the machine only. Back-mixing of the syrup film that flows down along the inside wall of the housing is minimised at crucial points. This is a particular advantage when separating the high-green syrup during the screen washing phase.

By setting the time after water washing, at which the green syrup flap closes and the high-green syrup flap opens, the syrup quality can be controlled in a reproducible manner.
Revolutionary basket design with elliptical openings

Decisive factors in assessing the performance of a sugar centrifugal are its availability and service life, in addition to efficiency.

By using the most advanced computational methods, BMA has been able to take a revolutionary step forward. Baskets for batch-type centrifugals have in the past always been provided with boreholes. BMA is the first centrifugal manufacturer worldwide to use, in its E-series machines, basket shells with elliptical outlet openings as a standard for batch centrifugal baskets (see Figure 2).

The advantage these elliptical openings have over cylindrical boreholes is that the peak stresses occurring in the basket shell during operation are reduced by more than 40%! This substantially increases the expected service life of the basket.

Since batch-type centrifugals have to meet very high demands, only stainless steel is used for their baskets. They are made from an advanced Duplex steel grade, which is a two-phase corrosion-resistant steel that combines the positive properties of ferritic stainless steel (high strength) and austenitic stainless steels (high ductility and resistance against corrosion).

To reliably provide the openings with a high-quality inside surface finish, a special method is used for introducing these openings into the basket shell. However since the elliptical openings produce a lower notch effect, the surface roughness plays a much lesser role for the service life of the basket than was the case with boreholes.

Unsurpassed safety

BMA’s attention has always been on the safety of its centrifugals, in addition to high sugar quality. The earlier generations of BMA centrifugals therefore already featured very high safety standards, and the E-series again incorporates a number of safety-specific improvements to reflect state-of-the-art technology.

By making systematic use of sensors, potentially critical operating conditions are detected and communicated at an early stage. Redundant oscillation monitoring features, for instance, reliably spot basket vibrations.

EU regulations, such as the equipment and product safety regulations and the machinery directive, have been consistently applied to ensure maximum safety. This obviously also implies the use of a failsafe control system (f-cpu).

Simplicity and automation for enhanced productivity

The integration of modern automation technology guarantees highest process reliability. Although sugar factories are increasingly making use of on-line measuring systems, e.g. for measuring colour and layer thickness, the full potential of this technology is often not utilised.

Since BMA is a solution provider with know-how not only in design solutions, but also in the process engineering and automation fields, on-line measurement features are directly integrated into the control system of the new E-series machine. This, for instance, allows the addition of wash water to be controlled as a real-time parameter as a function of layer thickness. With on-line sugar colour measurement, variations in quality are, in addition, detected without delay, so adaptations can be made from one batch to the next in order to maintain a constant sugar quality. Optional sensors for monitoring the discharging process are another feature that can be integrated for safe operation of the centrifugal. Excessive forces are reliably detected, and the discharging process can be influenced as required. The data also provide information about the centrifugation process itself, which allows the entire process to be optimised.

The innovations that have been implemented in the new E-series are characterised by their simplicity and the fact that maintenance-intensive components have been consistently eliminated. Here again, BMA relies on sensors and early information about operating conditions or maintenance needs. With the new generation of centrifugals, BMA has reduced maintenance requirements and, consequently, machine downtimes and has minimised life cycle costs. •
In the spring of 2011, BMA installed a prototype in the German sugar factory Plattling. This factory belongs to the Südzucker Group, the leading European sugar manufacturer (see Figure 3). Immediately after it had been commissioned, the E centrifugal was completely integrated into the production process and operated without interruption to the factory’s full satisfaction. All innovations were in parallel rigorously tested, both during the first thick-juice and beet campaigns.

The E machine was placed alongside existing white-sugar centrifugals on one common centrifugal platform. Both the massecuite feed and the sugar and syrup discharge systems, and the interfacing with the overall production process corresponded to the situation of new centrifugals that are finally installed in a factory. Sampling points for green and high-green syrup, and a tank for collecting the two syrups from one complete centrifugal batch were provided in addition.

When representatives of the factory entered the centrifugal platform for the first time they were totally impressed. Even though the machine was running at the time, there was absolutely no discernible noise. The operating status of the centrifugal, could only be discerned from the display unit.

The weight of massecuite that was fed into the centrifugal basket was checked several times, and the determined 1813 kg confirmed the nominal 1810 kg per batch, which is also what the type name of the medium-sized machine of the E-series reflects.

In white-sugar service, the machine, which was only equipped with a 200-kW drive, performed excellently with up to 28 batches per hour.

In extensive practical tests, the new syrup separation flume, too, proved to perform with the expected excellent syrup separation efficiency.

Criteria that can be used for assessing efficient syrup separation are the difference in green and high-green syrup purity, but also colour values. With 20% high-green syrup, which is a standard percentage of the complete amount of syrup, the colour of the high-green syrup could be reduced with the new syrup separation unit to half of what the normal external syrup separator would achieve.

The practical experience gained with the prototype machine already convincingly demonstrated that the novel design features translate into real benefits for the customer.

The vote of confidence for the centrifugal came from the customer, who not only kept the prototype, but also ordered another four machines of this series (Figure 4)!

**Figure 3.** E1810 prototype

**Figure 4.** Centrifugal station (in Plattling) equipped with four E1810 centrifugals and a BMA distribution mixer
Identification of three armyworm species (Lepidoptera: Noctuidae) using DNA barcodes and restriction enzyme digestion†

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abstract

Six species of sugarcane armyworms (Mythimna spp.) are known to occur in Mauritius, namely M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta and M. pyrausta. Due to the close resemblance of the adult moths, morphological distinction among the different species is difficult and may lead to misidentification. One new approach for their characterisation involves the use of DNA barcodes to analyse the sequence diversity within a short standardised segment of their genome. Polymorphism in the 5’ end of the mitochondrial cytochrome oxidase I (COI) gene is extensively used as a DNA barcoding system in Lepidopterans. In 2008, adult moths of M. insulicola, M. phaea and M. pseudoloreyi were reared from field-collected larvae. Two nucleic acid extraction methods were evaluated, both yielding high quality DNA for molecular studies. DNA extractions were performed from different body parts including abdomen, leg and wing. A ~700 bp PCR fragment amplified from the three species, using primers HCO2198/LCO1490, was digested using restriction enzymes. A combination of four enzymes RsaI, TaqI, PvuI and SacI successfully allowed distinction of the three species of armyworms tested. The PCR products from the three species were cloned and sequenced. A 658 bp fragment from each of M. insulicola, M. phaea and M. pseudoloreyi was submitted to Genbank and respectively recorded as Leucania insulicola, GQ353294; Leucania phaea, GQ353295; and Leucania loryei, GQ353296. Using the Barcode of Life identification engine (BOLD-ID), high sequence identities were obtained with Leucania species (Noctuidae: Hadeninae) – 99.54% for L. phaea and Leucania sp. (from Kenya), 100% for L. loryei and Leucania sp. and 99.85% for L. insulicola and L. striata (from Madagascar). The L. phaea sequence diverged by 7.3% and 10.6% from those of L. loryei and L. insulicola respectively. A sequence divergence value of 8.5% was observed between L. loryei and L. insulicola. DNA barcoding and sequencing could provide useful information for classification and characterisation of armyworms.

Keywords: armyworms, DNA barcodes, Mythimna spp., species identification

Identificación de tres especies de gusanos cogolleros (Lepidoptera: Noctuidae) usando códigos de adn y digestión enzimática

Seis especies de gusanos cogolleros de la caña de azúcar (Mythimna spp.) existen en Mauricio, en específico, M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta y M. pyrausta. Debido al gran parecido de las mariposas adultas, la identificación morfológica entre las distintas especies es difícil. Un nuevo enfoque para su caracterización involucra el uso de códigos de barra del ADN para analizar la diversidad de secuencia dentro de un pequeño segmento estándar de su genoma. El polimorfismo en el extremo 5’ del gen mitocondrial citocromo oxidasa I (COI) es usado ampliamente como un sistema de código de barras de ADN en los Lepidópteros. En 2008, mariposas adultas de M. insulicola, M. phaea y M. pseudoloreyi fueron criados a partir de larvas colectadas en el campo. Dos métodos de extracción de ácidos nucléicos se evaluaron, ambos rindiendo ADN de alta calidad para estudios moleculares. Extracciones de ADN se efectuaron de diferentes partes del cuerpo, que incluyeron abdomen, pata y ala. Un fragmento de ~700 pares de bases (pb) de cada una de las tres especies se amplificó por medio de la reacción en cadena de la polimerasa (PCR, por sus siglas en Inglés) usando los iniciadores (primers) HCO2198/LCO1490, luego de lo cual se digirió usando enzimas de restricción. Una combinación de cuatro enzimas RsaI, TaqI, PvuI y SacI permitió distinguir exitosamente a las tres especies de gusanos cogolleros evaluados. Los productos de PCR de las tres especies fueron clonados y secuenciados. Un fragmento de 658 pb de cada una de las especies M. insulicola, M. phaea y M. pseudoloreyi fueron enviadas a la base de datos “Genbank” y registrados, respectivamente, como Leucania insulicola, GQ353294; Leucania phaea, GQ353295; y Leucania loryei, GQ353296. Usando el mecanismo de identificación de Código de Barras de la Vida (en Inglés, Barcode of Life identification engine, BOLD-ID), se identificaron (con gran probabilidad) secuencias con las especies de Leucania (Noctuidae: Hadeninae)- 99.5% para L. phaea y Leucania sp. (de Kenia), 100% para L. loryei y Leucania sp., y 99.8% para L. insulicola y L. striata (de Madagascar). La secuencia de L. phaea fue diferente en un 7.3% y 10.6% de aquellas de L. loryei y L. insulicola, respectivamente. Un valor de divergencia de 8.5% se observó entre L. loryei y L. insulicola. La secuencia de L. phaea fue divergente en un 7.3% y 10.6% de aquellas de L. loryei y L. insulicola, respectivamente. El código de barras de ADN y la secuenciación pueden proveer de información útil para la clasificación y caracterización de gusanos cogolleros.

Identificação das três espécies de armyworm (Lepidoptera: Noctuidae) usando códigos de barras de DNA e reestrificação de enzima de digestão

Seis espécies de parasitoides larvais da cana (Mythimna spp.) são conhecidas por ocorrer na Maurícia, nomeadamente M. pseudoloreyi, M. loreyi, M. insulicola, M. phaea, M. tincta e M. pyrausta. Devido à semelhança da traça adulta, a distinção morfológica entre diferentes espécies é difícil.
Introduction

In Mauritius, infestations of sugarcane fields by armyworms belonging to the genus *Mythimna*, (Lepidoptera: Noctuidae) were initially reported in 1959 (MSIRI, 1960). In subsequent years, these pests did not pose a major threat to sugarcane and were under control. With the introduction of mechanised sugarcane harvesting and the adoption of trash blanketing practices, severe outbreaks were observed after 1992. Attacks by armyworms cause retardation in shoot development and this is more pronounced when associated with other stress factors including drought conditions. During severe outbreaks, total defoliation of affected fields may occur. To-date six species of sugarcane armyworms are known to occur in Mauritius, namely *M. pseudoloreyi*, *M. loreyi*, *M. insulicola*, *M. phaea*, *M. tincta*, and *M. pyrausta* (Ganeshan, 2007).

Control of armyworms is achieved through the use of insecticides. Chemical control can have negative impacts on the cane ecosystem in Mauritius, where a biological control strategy has always been adopted for the management of the cane ecosystem in Mauritius, where a biological control strategy has always been adopted for the management of sugarcane pests. Six species of parasitoids have been identified from *Mythimna* spp. in Mauritius (Ganeshan, 2001) and the entomopathogen *Metarhizium anisopliae*, has also been observed on larvae and pupae (Beehary-Pannar and Rajabalee, 1998). However, the application of biological control agents is reliant on accurate identification of the pest species involved and for *Mythimna* spp. this has been a major difficulty. Morphological distinction is problematic due to the close resemblance of the adult moths and this may lead to misidentification of species.

Molecular biology tools, particularly the use of ‘DNA barcodes’, can complement traditional morphologically based taxonomy to determine the identity of insect pest species (Hebert et al., 2003). This method relies on the sequence diversity within the *cytochrome-c oxidase I* (COI) gene of the mitochondrial DNA. Application of DNA barcodes in taxonomy is gaining momentum and there are currently various efforts worldwide in this area namely: Consortium for the Barcode of Life, All Lepidoptera Barcode of Life Initiative, Fish Barcode of Life Initiative, Canadian Centre for DNA Barcoding, Canadian Barcode of Life Network and All Birds Barcode of Life Initiative. These form part of the International Barcode of Life Initiative, which aims to have a global barcode system for all the species present on earth (Savolainen et al., 2005). The Barcode of Life Data Systems (BOLD) has thus been set-up (http://www.barcodinglife.org) and can be considered as an online barcoding information system for collection, management and analysis of DNA barcodes.

For Lepidoptera, which constitute the second most diverse insect order, with more than 180 000 known species and many more unknown ones, DNA barcodes are expected to identify more than 95% of species. In Costa Rica, in a study comprising of 4260 specimens of which 521 were *Lepidoptera* species, Hajibabaei et al. (2006) unambiguously identified 97.9% of the test species. Using DNA barcodes, it was shown that the sequence of *Diatrea saccharalis* shared 99% homologies with members of the Crambidae family (Bravo et al., 2008). Previously, there was confusion regarding classification of these moth borers in either the Pyralidae or Crambidae families. Similarly, it is expected that barcodes will provide more insight into the classification of the six *Mythimna* spp. in Mauritius. The genus *Leucania* has been reviewed and several species belonging to this genus were assigned to the *Mythimna* genus (Holloway et al., 1987). However, there is still some confusion on the taxonomic nomenclature of this genus, which needs revision.

The main objective of this project is to investigate the usefulness of DNA barcodes for distinguishing the six *Mythimna* spp. present in Mauritius.

Material and methods

Armyworm collection

Larvae were collected from sugarcane fields in 2008 and were reared to adult in the laboratory. Adult moths were identified using morphological characters (Ganeshan, 2007). The adult specimens were preserved in 90% ethanol until processed. Only three species were encountered: *M. pseudoloreyi*, *M. insulicola* and *M. phaea*. DNA was extracted from the three species (Table 1).

DNA extraction

An appropriate DNA extraction technique is a critical step for successful application of a DNA barcoding system for insects. It is important to have good quality DNA for amplification of the mitochondrial DNA fragment by the polymerase chain reaction (PCR). Two DNA extraction protocols were evaluated. Before homogenising, the specimens were removed from the alcohol and allowed to dry.
In the first method, the protocol described by Zhou et al. (2000) was followed for extraction of DNA from single moths. After removing the wings and legs, the moth was homogenised using a sterilised mortar and pestle (with 1 mL of extraction buffer – 10 mM Tris HCl (pH 7.5), 60 mM NaCl and 10 mM EDTA). 600 μL of the homogenate were transferred to a 2 mL microcentrifuge tube and an equal volume of post-grinding buffer (200 mM Tris HCl pH 9.0, 30 mM EDTA and 2% SDS) were added. 140 μg of proteinase K was added and the tubes were incubated in a water bath at 50°C overnight. Sodium acetate (pH 4.8) was added to a final concentration of 0.3 M. The contents of the tubes were transferred to a 15 mL falcon tube and an equal volume of phenol was added and centrifuged at 8000 rpm. The aqueous phase was recovered and extracted with an equal volume of chloroform:isoamyl alcohol (24:1). To the supernatant, two volumes of 95% ethanol were added and DNA precipitated with 1/10 volume of sodium acetate (3.0 M) and an equal volume of 95% ethanol (-20°C for 2 h). The DNA was recovered by centrifugation and following air-drying, was resuspended in 100 μL of sterile distilled water.

In the second method, a modified CTAB method was adopted. Adult moths devoid of wings and legs were homogenised in 1 mL CTAB buffer (2% CTAB, 1.4 M NaCl, 20 mM EDTA pH 8.0, 100 mM Tris-HCl pH 8.0, 0.1% mercaptoethanol and 200 μg proteinase K) using a mortar and pestle. 1 mL of the homogenate was transferred to a centrifuge tube and incubated for 45 min at 60°C. An equal volume of phenol: chloroform: isoamyl alcohol (25:24:1) was added and centrifuged at 8000 rpm. A second extraction step was performed on the supernatant using an equal volume of chloroform: isoamyl alcohol (24:1). DNA was precipitated with 1/10 volume of sodium acetate (3.0 M) and an equal volume of 95% ethanol (-20°C for 2 h). The DNA was pelleted by centrifugation and following air-drying, was resuspended in 500 μL of sterile distilled water.

Improvements to the two methods included an optional RNA digestion step. This was performed after the chloroform:isoamyl alcohol step; the supernatant was treated with 100 μg of RNase A and incubated at 37°C for 3 h. Attempts were also made to extract DNA from detached wings and legs of specimens (Table 1).

Amplification of DNA barcodes

Primer pair LCO1490/HCO2198 (Folmer et al., 1994) amplifies a ~700 bp fragment of the mitochondrial COI gene. PCR was performed in a total volume of 50 μL with 0.2 mM dNTPs, 1X PCR buffer, 0.3 μM of forward primer (LCO1490, 5' -GGTCAACAAATCCA TAAAGATATTGG) and reverse primer (HCO2198 5' -TAAACCTTCAGGGTG ACCAAAAATCA) and 1 U of Taq polymerase (Roche diagnostics, USA) and 1.5 μL of template DNA. The mixtures were set in a thermal cycler using the following thermal profile: denaturation at 94°C for 10 min followed by 35 cycles of 94°C for 30 s, 50°C for 30 s and 72°C for 1 min, and a final elongation step at 72°C for 10 min. Amplified fragments were separated by 1% agarose gel electrophoresis and visualised under UV light.

**Restriction fragment length polymorphism (RFLP)**

The ~700 bp PCR fragments amplified using HCO1490/HCO2198 were digested with enzymes RsaI, PvuII, TaqI and SacI as per manufacturer’s instructions (Roche Diagnostics). Digestion products were separated by 1% agarose gel electrophoresis and visualised under UV light.

**Cloning and sequencing**

One ~700 bp fragment amplified from each of the three species (M. pseudoloreyi, M. insulicola and M. phaea) was purified from agarose gel using the QIAquick Gel Extraction Kit (Qiagen) and cloned using the pGEM T Easy Vector system (Promega). Subsequently, the inserts were sequenced using an ABI 310 Genetic Analyser using the Big dye 3.1 Sequencing Kit (Applied Biosystems, USA) using universal primers.

**Sequence analysis**

COI DNA sequences from M. pseudoloreyi, M. insulicola and M. phaea were compared with other sequences from Genbank. The sequences were also used for species identification using the BOLD-IDS (barcode identification engine http://www.barcodinglife.org/). In order to establish the phylogenetic relationship of the three *Mythimna* spp., the primer sequences were trimmed and sequences were aligned with other sequences retrieved from

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* optional RNase digestion performed
Table 2. Sequences included in phylogenetic analysis of Mythimna sp.

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<td>Leucania stenographa*</td>
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* Sequences obtained from Barcode of Life database; † Name as accepted by Genbank (this study)

Results and discussion

Amplification of DNA barcodes

The ~700 bp fragment was successfully amplified with all 20 DNA extracts, AR001-AR020 (Figure 1).

Extracts obtained using the Zhou et al. (2000) method (AR001-004 and AR013-016) as well as the remaining ones (CTAB method) were suitable for the generation of DNA barcodes from Mythimna spp.

The optional RNase step was performed for only three extracts (AR011, AR017 and AR018 in Lanes 11, 17 and 19 respectively) and there was not much difference in product amplification.

Restriction fragment length polymorphism (RFLP)

The ~700 bp products amplified with primers HCO1490/LCO2198 were digested using restriction enzymes Rsal, TaqI, SacI and Pville (Figure 2). A combination of restriction patterns with at least two enzymes allowed discrimination between the three Mythimna spp. tested. Rsal and TaqI could differentiate M. pseudoloreyi and M. insulicola from M. phaea.

The SacI recognition site, which is only present in the M. pseudoloreyi fragment, was used to separate M. pseudoloreyi from M. insulicola. Enzyme Pville also confirmed the slight difference existing between M. pseudoloreyi and M. insulicola (Figure 2), but the digested product was very close to 700 bp.

The PCR-RFLP described above is a simple technique for differentiating the three armyworm species M. pseudoloreyi, M. insulicola and M. phaea. In 2009, additional specimens including M. loreyi, M. tincta, and M. pyrausta will be collected and the method further validated.

Sequence analysis

Sequences obtained from cloned HCO1490/LCO2198 PCR products of M. insulicola, M. phaea and M. pseudoloreyi were edited to remove the primer region and deposited in Genbank. The curators have accepted the entries as Leucania insulicola, L. phaea and L. loreyi respectively (GQ353294-6). These names will be used for further discussion in the current paper in order to avoid confusion. It is expected that, with further analysis of barcode data from the three other Mythimna species in Mauritius (M. loreyi, M. tincta and M. pyrausta), the issue of classification will be clearer.

Analysis in the Barcode of Life Identification Engine (BOLD-ID) was performed using the full barcodes and very high (99%) homologies were obtained with specimens belonging to the Leucania genus (Noctuidae; Hadeninae).
Table 3. Sequence similarities of *Leucania* (*Mythimna*) from this study with those from related species

<table>
<thead>
<tr>
<th>Species</th>
<th>Homologies</th>
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<tr>
<td><em>L. insulicola</em></td>
<td>99.85% with <em>Leucania striata</em> (LTOL390-09)- from Madagascar</td>
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<tr>
<td><em>L. phaea</em></td>
<td>99.54% with unidentified <em>Leucania</em> sp. (PMAN304-09)- from Kenya</td>
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<tr>
<td><em>L. loreyi</em></td>
<td>100% with unidentified <em>Leucania</em> sp. (PMAN310-09)- from Australia</td>
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</table>

Figure 2. Restriction digestion of HCO1490/LCO2198 PCR products using enzymes Rsal, TaqI, SacI and PvuII. Lanes 1-12 consist of the three *Mythimna* spp. as specified, M is 100 bp ladder.

(Tables 3). However, these sequences are not currently publicly available and requests were made to the authors for access. Interestingly, the closest matches were either regional specimens, e.g. *L. striata* (LTOL390-09) was collected in Madagascar while the unclassified *Leucania* sp. (PMANL304-09) was collected in Kenya, or pests of sugarcane: specimen *L. stenographa* (ANICB181-06) originates from Australia where this species (= *L. loreyimima*) is known to infest sugarcane plantations (Edwards, 1992). The sequences from this study were compared with those from other *Mythimna* and *Leucania* species publicly available from BOLD. The COI sequence of *L. insulicola* (GQ353294) diverged by 10.6% from *L. phaea* while there is a divergence of 7.3% from *L. loreyi*. For *L. insulicola* and *L. loreyi*, there is a sequence divergence of 8.5% (Table 4). With such high divergence at nucleotide level, it is very easy to distinguish between the three species being studied. The average overall mean divergence for the 15 species considered in Table 4 is 8.5% (±0.7% SE). It should be noted that only *Mythimna* and *Leucania* sp. have been included in Table 4.

Using sequences of the mitochondrial COI gene of moths, Hebert et al. (2003) showed that there is an average sequence divergence of 0.25% for conspecific individuals while for congeneric species, an average of 6.5% was observed. For the sugarcane stem borer, *Busseola* sp., interspecific divergence of > 4.5% has been reported (Assefa et al., 2007). However, caution should be made using COI sequence divergence information for species delimitation (Whinnett et al., 2005). It is also important to consider morphological characteristics for taxonomy purposes.

A phylogenetic tree was constructed using the three *Leucania* (*Mythimna*) spp. from this study and selected related sequences from Genbank and high percentage divergence among the three sequences indicates the occurrence of three distinct species. Divergence of 7.3% and 10.6% was observed between *L. phaea* sequence and those of *L. pseudoloreyi* and *M. insulicola* respectively. The latter two species had 8.5% sequence divergence. DNA barcoding is effective and very convenient for distinguishing closely related and morphologically similar species.

Conclusions

A simple and quick method for distinguishing among *L. insulicola*, *L. phaea* and *L. pseudoloreyi*, based on PCR-RFLP of part of the mitochondrial COI gene is described in this study.

At nucleotide level, the three species shared high homologies with moths of *Leucania* spp., which occur either in neighbouring countries e.g Madagascar or as pests of sugarcane in Australia. These sequences have currently been deposited in Genbank as *L. insulicola*, *L. phaea* and *L. loreyi*. The species clustered within the *Mythimna*/*Leucania* group.

Acknowledgements

The authors wish to thank the following persons from Barcode of Life Data Systems (BOLD) for providing non-public barcode sequence data: Dr Scott Miller (Smithsonian Institution, Washington, USA), Dr Graeme Cocks (Lepidoptera, of Townsville, Australia) and Dr Kim Mitter (Collection Manager, ATOLep Collection, University of Maryland, USA).

Figure 3. These species clustered within the *Mythimna*/*Leucania* group.

† Paper presented at the XXVIIth Congress of the International Society of Sugar Cane Technologists, Veracruz, Mexico, March 2010 and published here with the agreement of the Society.
Table 4. Average pairwise Kimura 2 parameter distances (below diagonal) and standard errors (above) between L. phaea, L. insulicola and L. loreyi and selected sequences

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References


Identification of intergeneric hybrids between *Erianthus arundinaceus* and *Saccharum spontaneum* through STMS markers

P. Govindaraj 1*, A. Balamurugan 2 and U.S. Natarajan 3

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2 Research Assistant, UPASI, Valparai, India.
3 Retired Principal Scientist, Sugarcane Breeding Institute, Coimbatore, India.

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**abstract**

*Erianthus arundinaceus*, a genus in *Saccharum* complex with high biomass production and resistance to biotic stresses is one of the potential candidates to broaden the genetic base of modern sugarcane varieties. Except some advancements reported on *Erianthus* introgression in India and Australia, attempts in the past four decades did not result in significant progress due to the inherent difficulty in making such crosses, transmission of n+n gametes and hybrid sterility. *Saccharum spontaneum* was used as bridge species to overcome these barriers but identification of true intergeneric hybrids with morphological markers was difficult. Fifteen sugarcane genome specific STMS markers were successfully used in identifying four suspected hybrids between two *S. spontaneum* (SES 286 -SS1 and SES 571 -SS2) and one *Erianthus arundinaceus* (IK 76-92-EA). Among the 15 primers used, 13 and 12 were polymorphic between EA and SS1 and EA and SS2 respectively. The polymorphic markers ranged from 1 (NKS 12, 46) to 12 (NKS 21) among the progeny of EA x SS1 and 2 (NKS 45, 15, 38, 40) to 7 (NKS 23) among the progeny of EA x SS2. While the hybrid nature of three progeny of the cross EA x SS1 was confirmed by the distinct presence of 57, 53 and 56 male specific markers respectively, hybrid nature of the progeny between EA x SS2 was confirmed by the presence of 42 male specific markers. The study clearly demonstrated the efficiency of STMS markers to generate large polymorphism and identification of true hybrids.

**Keywords:** *Erianthus arundinaceus*, intergeneric hybrids, microsatellite markers, *Saccharum spontaneum*

Identificación de híbridos intergenéricos entre *Erianthus arundinaceus* y *Saccharum spontaneum* mediante marcadores STMS

*Erianthus arundinaceus*, un género del complejo *Saccharum*, que posee una alta producción de biomasa y resistencia a estrés biológico, es uno de los candidatos potenciales para ensanchar la base de las variedades modernas de caña de azúcar. Aparte de algunos avances informados sobre la introgresión de *Erianthus* en India y Australia, las tentativas en las últimas cuatro décadas no resultaron en progresos significativos dada la dificultad intrínseca para realizar esas cruces, a saber transmisión de gametos n+n y esterilidad de los híbridos. Se utilizó *Saccharum spontaneum* como especie puente para sobrepasar esas barreras, pero la identificación de los verdaderos híbridos intergenéricos mediante marcadores morfológicos era dificultosa. Se utilizaron exitosamente quince marcadores STMS específicos del genoma de la caña de azúcar para identificar cuatro híbridos probables entre dos *S. spontaneum* (SES 286 -SS1 y SES 571 -SS2) y un *Erianthus arundinaceus* (IK 76-92-EA). Entre los quince primers utilizados, 13 y 12 eran polimórficos entre EA y SS1 y EA y SS2 respectivamente. Los marcadores polimórficos variaron desde 1 (NKS 12, 46) hasta 12 (NKS 21) en la progenie de EA x SS1 y 2 (NKS 45, 15, 38, 40) a 7 (NKS 23) en la progenie de EA x SS2. En tanto que la naturaleza híbrida de tres progenies de la cruza EA x SS1 se confirmó por la presencia distintiva de 57, 53 y 56 marcadores masculinos específicos respectivamente, la naturaleza híbrida de la progenie entre EA x SS2 se confirmó por la presencia de 42 marcadores masculinos específicos. El estudio muestra la eficiencia de los marcadores STMS para producir polimorfismo amplio y para la identificación de híbridos verdaderos.

Identificação dos híbridos intergenéticos entre *Erianthus arundinaceus* e *Saccharum spontaneum* através de marcadores STMS

*Erianthus arundinaceus*, um género del complejo *Saccharum*, com produção de biomassa elevada e resistência ao stress bióticos é um dos potenciais candidatos para alargar a base genética de variedades modernas de cana. Exceto por alguns avanços relatados a introgressão de *Erianthus* na Índia e na Austrália, tentativas nas últimas quatro décadas não resultaram em progresos significativos devido à dificuldade inerente em fazer tais cruzamentos, transmissão de gametas n e esterilidade do híbrido. *Saccharum spontaneum* foi usado como espécie de ponte para superar essas barreiras mas a identificação dos verdadeiros híbridos com marcadores morfológicos foi difícil. Quinze mercados específicos de genome STMS foram usados com sucesso na identificação de quatro híbridos suspeitos entre dois *S. spontaneum* (SES 286 -SS1 and SES 571 -SS2) e um *Erianthus arundinaceus* (IK 76-92-EA). Entre as 15 primers usadas, 13 e 12 eram polimórficos entre EA e SS1 e EA e SS2 respectivamente. Os marcadores polimórficos variaram de 1 (NKS 12, 46) a 12 (NKS 21) entre a descendência de EA x SS1 e 2 (NKS 45, 15, 38, 40) a 7 (NKS 23) entre a descendência de EA x SS2. En tanto que la naturaleza híbrida das três descendências do cruzamento EA x SS1 foi confirmada pela presença distinta de marcadores específicos masculinos 57, 53 e 56 respectivamente, natureza híbrida de descendência entre EA x SS2 confirmou a presença de 42 marcadores masculinos específicos. O estudo demonstrou claramente a eficiência dos marcadores de STMS para gerar grande polimorfismo e identificação dos verdadeiros híbridos.
Introduction

Saccharum is an important genus of the Andropogoneae tribe of the grass family Poaceae. The closely related genera consisting of Erianthus, Narenga and Sclerostachya were grouped under the Saccharum complex. Cytomorphological evidence showed that in addition to the Saccharum genera, Miscanthus, Erianthus and Sclerostachya are also involved in the origin of cultivated sugarcane (Cordeiro et al., 2003) and are supposedly a closely related interbreeding group. But only a limited number of interspecific hybridization events between Saccharum officinarum (2n = 80, basic chromosome number x = 10) and S. spontaneum (2n = 48-124, basic chromosome number x = 8) (Berdling and Roach 1987) were exploited for developing commercial hybrids worldwide. Although new species clones were included in breeding programmes in Sugarcane Breeding Institute, India and CSR team in Fiji during 1960’s, most of the world germplasm collections were unutilized. Improving the genetic base of the modern sugarcane cultivars worldwide is the major concern and to increase the genetic base sugarcane breeders are constantly introgressing genes from related wild species. Wild species of Saccharum and related genera like, S. spontaneum, S. robustum Brandes et Jeswiet ex Grassl in Hawaii (Heinz 1967) and Miscanthus Anderss. spp. in Taiwan (Lo et al. 1986; Alix et al. 1999), Erianthus spp. (Tai and Miller 1988; Legendre 1989; D’Hont et al. 1995; Cai et al. 2005, Krishnamurthi et al., 2004 and 2007 Shanmugasundaram et al., 2010) were introgressed in sugarcane indicating the ability of the Saccharum spp. to tolerate alien genomes in hybrid combinations. The ability of sugarcane genome to produce viable hybrids when crossed with related genera and even with genera outside the Saccharum complex including sorghum and maize had been attributed to the buffering effect of its polyploid genome (Janaki Ammal, 1941, Gupta et al., 1976) and encouraged several workers to use related species and genera in hybridization programmes.

Erianthus arundinaceus, a related genus of Saccharum has high potential of biomass production, multiple ratooning, drought resistance and disease and pest resistance (Nair et al., 2005, Mukunthan, 2000, Bakshi Ram et al., 2001). Introgression of Erianthus genome into sugarcane is always challenging to sugarcane breeders because of wide genetic distance between these genera (Piperidis, 2000) and frequent occurrence of low pollen fertility in the hybrids (Piperidis, 2010). In most of the crosses n+n transmission occurs and a number of back crosses are required to recover the S. officinarum genome (Piperidis, 2010a) and to eliminate the undesirable traits transmitted from E. arundinaceus. In order to realize 2n+n transmission, it was conceptualized to use S. spontaneum as bridge species as 2n+n is almost the rule when S. officinarum is crossed with S. spontaneum (Piperidis, 2010). In addition to this S. spontaneum is a good source of incorporating fertility, which is required in the intergeneric hybrids for further genetic improvement. Hence in the present study, S. spontaneum was used as a bridge species for the introgression of E. arundinaceus as a new approach and crosses were made between these two genera.

Success of intergeneric crosses in sugarcane is relatively low and very often such crosses result in large number of selfs. Identification of genuine hybrids and distinguishing them from selfed progenies in intergeneric crosses involving both parents from wild species is difficult. Verification of hybrid progeny from interspecific or intergeneric crosses in sugarcane improvement is essential before used in introgression studies (Lee et al. 1998, Pan et al., 2006a). Molecular techniques along with the morphological descriptors would be quite useful in identification and characterization of intergeneric hybrids of Saccharum (D’Hont et al., 1995; Alix et al., 1999). Among the DNA based markers, microsatellites or SSR are more reliable for fingerprinting of sugarcane clones and have the potential to be used in studies on male specificity (Cordeiro et al., 2003).

Large number of sugarcane microsatellites or simple sequence repeats (SSRs) have recently been developed from an enriched microsatellite library and were shown to have the capacity to distinguish between sugarcane genotypes because of their ability to detect large numbers of alleles (Cordeiro et al., 2000; Pan et al., 2003). Pan (2006) studied 221 microsatellite markers with US germplasm and established the usefulness of SSR markers in sugarcane germplasm evaluation, variety identity tests, cross fidelity assessment, and polycross paternity analysis. In this paper, first report on efficiency of microsatellite markers in identifying true Erianthus arundinaceus x S. spontaneum hybrids is demonstrated.

Materials and methods

Materials

The study was carried out using two crosses both generated at Sugarcane Breeding Institute, Coimbatore, India. E. arundinaceus (IK 76-92) was crossed with two S. spontaneum (SES 286 and SES 571) clones following conventional lantern method of crossing and fluff were collected (Table 1). E. arundinaceus (IK 76-92) was used as female and high pollen fertile S. spontaneum (SES 286 - 90.8 % and SES 571 - 93.5 % - pollen fertility was determined by in vitro test) was used as male parents. The fluff was sown in raised nursery beds and the seedlings were examined for selecting suspected hybrids. Among the progenies visible selfs were removed in the seedling stage itself and four progenies which showed early vigour and presence of dewlap were separated and planted as suspected hybrids. The seedlings

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Progeny number</th>
<th>Parentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GBB 013501</td>
<td>IK 76-92 (Erianthus arundinaceus)</td>
</tr>
<tr>
<td>2</td>
<td>GBB 013502</td>
<td>IK 76-92 (Erianthus arundinaceus)</td>
</tr>
<tr>
<td>3</td>
<td>GBB 013504</td>
<td>IK 76-92 (Erianthus arundinaceus)</td>
</tr>
<tr>
<td>4</td>
<td>GBB 013102</td>
<td>IK 76-92 (Erianthus arundinaceus)</td>
</tr>
</tbody>
</table>
were transplanted in field and analyzed through morphological and SSR markers. Both the parents and their hybrids were characterized for confirming hybridity.

Morphological characterization

All the parents and hybrids were analyzed for presence of dewlap, leaf color, leaf width (cm), leaf length (cm), number of root eyes, spread of root eyes, cane thickness (cm), number of tillers at 11th month, presence of wax in stem and pollen fertility following standard procedures (Table 2).

DNA extraction

DNA was extracted from four putative hybrids between two S. spontaneum (SES-286-SS1 and SES-571-SS2) and one E. arundinaceus (IK-76-92-EA) following cTAB method. DNA was quantified spectrophotometrically using Nanodrop™ and the final concentration was adjusted to 10ng/μl. Quality of the DNA was checked on 1% agarose gels.

PCR amplification and separation of the PCR products

PCR were performed in 10μl volume containing 20ng of genomic DNA, 20pmol of each forward and reverse primers, 100μM of each dNTPs, 0.5U of Taq DNA polymerase (M/s. Intron). DNA was amplified by 15 STMS primer pairs (Table 3) with respective annealing temperature. The PCR reactions were carried out in Eppendorf gradient thermal cycler and the PCR products were size separated by Poly Acrylamide Gel Electrophoresis (PAGE). PCR temperature regimes was standardized as 94°C for 5min (initial denaturation) followed by 35 cycles of 94°C for 1 min (denaturation), appropriate annealing temperature ranging from 55°C to 58°C specific to individual primers for 1 min (extension) and a final extension temperature at 72°C for 5

Table 2. Morphological characterization of parents and the putative hybrids

<table>
<thead>
<tr>
<th>Descriptor of.dwlap</th>
<th>SES 286</th>
<th>013501</th>
<th>013502</th>
<th>013504</th>
<th>IK 76 - 92</th>
<th>013102</th>
<th>SES 517</th>
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<tbody>
<tr>
<td>Presence of dewlap</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Leaf color</td>
<td>Dark Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td>Green</td>
<td></td>
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<tr>
<td>Leaf width (cm)</td>
<td>1.2</td>
<td>1.2</td>
<td>1.1</td>
<td>1.4</td>
<td>3.8</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Leaf length (cm)</td>
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<td>101</td>
<td>110</td>
<td>121</td>
<td>117</td>
<td>102</td>
<td>120</td>
</tr>
<tr>
<td>No of root eyes rows</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Spread of root eyes</td>
<td>Sparse</td>
<td>Sparse</td>
<td>Sparse</td>
<td>Sparse</td>
<td>Sparse</td>
<td>Sparse</td>
<td>Sparse</td>
</tr>
<tr>
<td>Cane thickness</td>
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<td>9.6</td>
<td>9.1</td>
<td>11.9</td>
<td>17.7</td>
<td>8.8</td>
<td>7.1</td>
</tr>
<tr>
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<td>13</td>
<td>54</td>
<td>6</td>
<td>42</td>
<td>3</td>
<td>65</td>
</tr>
<tr>
<td>Presence of wax in stem</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>NIL</td>
<td>High</td>
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</tr>
<tr>
<td>Pollen fertility</td>
<td>90.8</td>
<td>8.97</td>
<td>31.7</td>
<td>29.82</td>
<td>73</td>
<td>15.6</td>
<td>93.5</td>
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Table 3. Details of STMS primers used

<table>
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<tr>
<th>Sl. No</th>
<th>Marker name</th>
<th>Source sequence</th>
<th>SSR motif</th>
<th>Forward primer (5’ - 3’)</th>
<th>Reverse primer (5’ - 3’)</th>
<th>Ta (°C)</th>
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<tbody>
<tr>
<td>1</td>
<td>NKS 12</td>
<td>SHY293484</td>
<td>(ag)23</td>
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<td>ccgtatccatagtctgcatg</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>NKS 14</td>
<td>SHY293487</td>
<td>(ga)22</td>
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<td>ccaacagctgtctccttctt</td>
<td>58</td>
</tr>
<tr>
<td>3</td>
<td>NKS 15</td>
<td>SHY293488</td>
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<td>taagtggcctagggctaaaaa</td>
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</tr>
<tr>
<td>4</td>
<td>NKS 16</td>
<td>SHY293489</td>
<td>(ag)23</td>
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<td>ctgctctgtcttattgagc</td>
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</tr>
<tr>
<td>5</td>
<td>NKS 20</td>
<td>SHY293494</td>
<td>(ga)18</td>
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<td>tttactatgaccaagataagc</td>
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<tr>
<td>6</td>
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<td>SHY293495</td>
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<td>ctgtgctctgggaatctttc</td>
<td>58</td>
</tr>
<tr>
<td>7</td>
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<td>SHY293498</td>
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<td>tccggaggtgatgatcattt</td>
<td>58</td>
</tr>
<tr>
<td>8</td>
<td>NKS 27</td>
<td>SHY293502</td>
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<td>taattgctctggtgctcaaat</td>
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<td>9</td>
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<td>10</td>
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<td>12</td>
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<td>14</td>
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<tr>
<td>15</td>
<td>NKS 61</td>
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<td>(gt)16</td>
<td>tggccacgtgcaagctttt</td>
<td>aggaactctcccaagacaca</td>
<td>55</td>
</tr>
</tbody>
</table>
min. (Govindaraj et al., 2005). PCR products were size separated by passing through 8% Acrylamide (29); Bisacrylamide (1) gel matrix in 1X TBE buffer under 140V current for 3.30 hrs.

Staining and scoring

Gels were stained in ethidium bromide for 15 minutes and destained in Milli Q water for 30 minutes. The banding pattern was viewed under UV illumination in Alpha Imager and documented electronically. Scoring was done on the basis of presence (1) and absence of band (0) and number of markers was determined based on the number of clear bands detected. Molecular weights of markers were determined using the software Alpha imager.

Results and discussion

Modern sugarcane cultivars are the complex hybrids involving members of Saccharum complex. After rapid gain achieved through nobilization during 1920’s steady but only marginal improvement in productivity was observed in the last few decades probably due to usage of limited gene pool in sugarcane breeding. Hence base broadening programme were initiated notably in India and Fiji with interspecific and intergeneric hybridization involving related genera including Erianthus arundinaceus (Premachandran et al., 2006, Krishnamurthi et al., 2004, Shanmugasundaram 2010). Attempts to cross E. arundinaceus with the Saccharum species in the past four decades resulted in limited success for the development of commercial varieties except few successful reports (Krishnaswamy et al., 2007; Piperidis et al., 2010). Crosses between sugarcane and E. arundinaceus have been generally difficult to perform, and distinguishing true hybrids from progeny frequently arising from self-pollination, contamination with other Saccharum spp. pollen or androgenetic derivatives through morphological traits can be difficult and even misleading (Tai, 1989 and Shanmugasundaram et al., 2010). Due to small flower size and height of the inflorescence, hand emasculation is impractical and attempts to employ other emasculation techniques including hot water (Divinagracia, 1980; Krishnamoorthy, 1997; Heinz and Tew, 1987; Pan et al., 2006a) and chemical treatments (Soeprijanto and Sukardo, 1989) did not ensure complete male sterility. In some cases the hybrids may be very weak and the robust selfed progenies of E. arundinaceus may suppress the growth of genuine hybrids in germination stage itself (Piperidis et al., 2000). Even cytological studies may not confirm the hybrid nature due to less difference in chromosome number and elimination of chromosomes. Hence there has been an increasing demand for both species specific and trait specific DNA markers (Pan 2001 and Pan et al., 2001). Identification of true hybrids is possible in the early stage if appropriate DNA markers (Pan et al., 2006) along with distinct morphological markers are employed.

E. arundinaceus (EA) and S. spontaneum (SS) are good sources of several agronomically important genes for the development of superior sugarcane varieties. However, when they are crossed with S. officinarum (SO), the noble cane, the progenies from crosses with EA have n+n chromosomes (Piperidis et al., 2010), while crossing with SS resulted in 2n+n transmission. AFLP analysis of the hybrids between SO (2n = 80) and Erianthus rockii (2n = 60) confirmed the n+n transmission (Aitken et al., 2007). It is desirable to transmit the whole chromosome complement of SO to introgress maximum number of noble genes into commercial varieties. The 2n+n transmission also helps to bring in commercial traits of SO parents in just one or two backcrosses more rapidly than in n + n transmission (Sreenivasan et al., 1987). It is an established fact that whenever S. spontaneum was used as male parent in the introgression programme with S. officinarum 2n + n is almost a rule up to two back cross generations. The progenies produced from crossees involving S. spontaneum also showed greater pollen fertility. A new approach to achieve 2n gamete transmission from EA and to improve the fertility of the progenies is to use SS as bridge species and then cross and back cross with S. officinarum i.e. (SO X SO X (EA X SS)) hence crosses between EA and SS were made. In the first step E. arundinaceus was crossed with two S. spontaneum clones with high pollen fertility.

Morphological features of the suspected hybrids

The morphological and agronomical features of the hybrids are presented in Table 4. The prominent distinguishing morphological marker was dewlap which was present in the male parents (SS1 and SS2) and in the hybrids while it was absent in EA. Premachandran et al., 2006 identified suspected hybrids from E. arundinaceus and S. spontaneum with the presence of dewlap at the junction of the leaf blade and leaf sheath, a Saccharum feature not present in the Erianthus. The other important indicative trait was number of root eyes rows. While EA had single root eye row all the hybrids had two rows as observed in SS. Wax was absent in EA while in the hybrids and SS it was present prominently. All the hybrids except GBB 013502 had poor tillering ability which ranged from 3-13 but both the parents had high number of tillers (>42). In general, Erianthus are robust and high biomass producer with large number of tillers and thick culms. S. spontaneum are thin canes, high tillering with narrow leaves. It is expected that the hybrids should be intermediate or better, but in the present study tiller number were very low indicating tillering of the hybrids depends upon the type of S. spontaneum used. Cane thickness and leaf width reduced considerably and close to SS compared to EA. Even though some morphological characters had given indication that the progenies might be true hybrids, they could not be proven beyond doubt. It was interesting to note that although the morphological data were analyzed for individual progeny, the hybrids varied for all traits as expected from heterozygous and heterogeneous individuals. These results clearly indicated that additional markers are required for confirmation of these suspected hybrids hence SSR markers were used further.

Flowering was observed in all the hybrids, but most of them showed high male sterility (68 - 91%). One of the main objectives of using SS in the introgression programme is to retain the male fertility in the hybrids so that they can be used in further cross or back cross programme. To further utilize them in breeding programmes and to improve the fertility, crosses were made using these hybrids as female parents and SO X SS as male parent. Only two vigorous hybrids were obtained from the progenies but both of them were male sterile. Further, open pollinated fluff and crosses with large number of co-canees, S. spontaneum and E. arundinaceus resulted in very few progenies indicating the possibility of female sterility also.
### Table 4. Number of polymorphic markers produced by STMS primers

<table>
<thead>
<tr>
<th>S. No</th>
<th>Marker name</th>
<th>Total no. of bands produced</th>
<th>IK76-92 and SES 286</th>
<th>IK76-92 and SES 517</th>
<th>Polymorphic PCR product range (bp)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>NKS 12</td>
<td>24</td>
<td>1</td>
<td>3</td>
<td>211 - 290</td>
</tr>
<tr>
<td>2</td>
<td>NKS 14</td>
<td>19</td>
<td>9</td>
<td>4</td>
<td>209 - 444</td>
</tr>
<tr>
<td>3</td>
<td>NKS 15</td>
<td>19</td>
<td>3</td>
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<td>43</td>
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**Figure 1.** Identification of true hybrids with NKS 12, NKS 14 and NKS 15 primers

**Figure 2.** Identification of true hybrids with NKS 16, NKS 21 and NKS 49 primers

Lane 1 = 500bp ladder, Lane 2-8 = NKS 12, Lane 9-15=NKS 14, Lane 16-22=NKS 15.

Arrows indicate the polymorphic markers between the parents
Identification of hybrids through SSR markers

Identification of polymorphic markers between the parents is of prime importance for confirming the putative hybrids through molecular markers. Potential of microsatellite markers for sugarcane genome analysis were also reported by Janoo et al. (2001), Zhang et al. (2001) and Pan et al. (2002 and 2003). Hence microsatellite markers were preferred to generate polymorphic markers between the parents. In the present study, 15 sugarcane genome specific STMS (Sequence Tagged Microsatellite Sites) markers developed by our group utilizing sugarcane genomic sequences obtained from EMBL database were successfully utilized for the identification of the hybrids. Among the 15 primers (Table 2) used, 13 were polymorphic between EA and SS1 and 12 were polymorphic between EA and SS2. In general, number of markers generated by EA was very less compared to SS. This might be due to the fact that the primers were designed utilizing the sequences from sugarcane hybrids having no EA genome in their pedigree. However Alwala et al., 2006 reported presence of several markers in EA which were absent in SS. EA had low level of polymorphism compared with Saccharum (Besse et al., 1997a, 1998) based on RFLP and AFLP analyses hence highly polymorphic markers are suggested to distinguish between clones.

All the primer combination used in the study except NKS 20 generated multiple bands with the maximum number of markers generated by NKS 16(27) with an average of 17.3 markers per primer. High number of markers was due to amplification of loci on each of the estimated 10-14 homologous/homoeologous chromosomes within a homology group. In the earlier studies, each SSR amplified 4.9 alleles on average within an F 1 mapping population (Aitken et al. 2005) and an average of eight alleles were amplified by each SSR within unrelated germplasm (Cordeiro et al., 2000). The large number of markers amplified in the sugarcane parents by each SSR primer in the present study allowed us to effectively verify the intergeneric hybrids. However, they were not sufficient enough to quantify the amount of Erianthus material transferred to the F 1 generation.

The polymorphic markers between the parents ranged from 1 (NKS 12, 46) to 12 (NKS 21) for the progenies EA x SS1 and 2 (NKS 45, 15, 38, 40) to 7 (NKS 23) for the progeny EA x SS2 (Table 3). An average of five polymorphic markers per primer pair were found, which is sufficient enough to use them in marker analysis. Since the parents are from distantly related genera (Sobral et al., 1994; Al Janabi et al., 1994; Burnquist et al., 1992, Nair et al., 1999) more polymorphic markers were found. Strong molecular differentiation between Erianthus and Saccharum was previously demonstrated with rDNA spacers (Al-Janabi et al., 1994), RFLP (Burnquist et al., 1992), AFLP (Besse et al., 1998), 5S RNA intergenic spacers (Pan et al., 2000) and TRAP markers.

### Table 5. Estimate of similarity between E. arundinaceus (EA) and S. spontaneum (SS)

<table>
<thead>
<tr>
<th>S. No</th>
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<th>Total no. of bands produced</th>
<th>Number of monomorphic markers between EA and SS</th>
<th>% of similarity</th>
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### Table 6. Number of male specific markers that identified the hybrids

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<td>53</td>
<td>56</td>
<td>42</td>
<td>272</td>
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markers (D’Hont et al., 2006).

The amplified product size of the polymorphic markers ranged from 33bp (NKS 48) to 684bp (NKS 23) among three progenies of EA x SS1 (GBB 013501, GBB 013502, GBB 013504) and 39bp (NKS 40) to 639bp (NKS 23) for the progeny of EA x SS2 (GBB 013102). The number of markers confirmed the hybridity by the presence of S. spontaneum specific markers were analyzed (Table 4). While the hybridity of three progenies of the cross EA x SS1 was confirmed by the presence of 57, 53 and 56 S. spontaneum specific distinct markers respectively, hybridity of the progeny between EA x SS2 was confirmed by the presence of 42 male specific distinct markers (Figures 1 and 2). Thus each hybrid was confirmed by the presence of more than 40 specific markers. Among the hybrids, GBB 013504(56) had the maximum and GBB 013102(42) had the minimum number of male specific markers.

It is interesting to note that out of 15 primers used, 10 primers identified all the hybrids indicating that only a few microsatellite primers are sufficient in identifying the hybrids (Govindaraj 2005). Pan et al. (2007) demonstrated that the molecular approach of fingerprinting progeny to confirm parentage prior to field planting even with only one microsatellite marker might substantially increase selection efficiency. Present study also has opened way for identifying large number of seedlings in the early stage of selection with limited number of primers thus saving resources and time. A number of hybrids between E. arundinaceus and S. officinarum have been verified using 55 rDNA molecular markers (D’Hont et al., 1995, Besse et al., 1997b, Alix et al., 1999, Piperidis et al., 2000, Shanmugasundaram et al., 2010), inter-Alu sequences (Alix et al., 1998) and genome in situ hybridization (Piperidis and D’Hont 2001). The study clearly showed that these sugarcane specific STMS markers have the potential to produce large polymorphism and can be effectively used for identification of true hybrids. The identified hybrids are currently used for back crossing with sugarcane hybrids for introgression of Erianthus genome.

Sugarcane breeders are constantly searching for new genetic resources for breaking yield plateau witnessed in the past few decades. This is expected to widen the genetic base of the parental population and to facilitate incorporation of new traits such as high yield, quality and tolerance to biotic and abiotic stresses into sugarcane cultivars. Early screening and identification of true intergeneric/ interspecific hybrids is an important step towards rejecting the progeny which are not hybrids. In the absence of reliable morphological markers, molecular markers have shown to be very effective in identifying true interspecific/intergeneric hybrids in sugarcane. Using SSR markers in the present study, a strong molecular differentiation was detected between the S. spontaneum and E. arundinaceus allowing identification of true hybrids with the presence of S. spontaneum specific bands. This is the first report where hybrid progeny generated from E. arundinaceus and S. spontaneum have been verified by SSR molecular data. The results obtained assumes greater significance in the base broadening programme involving E. arundinaceus for the development of sugarcane varieties with new sources of genes for biomass, ratooning ability and resistance to biotic stresses. This would save time and resources in retaining genuine hybrids prior to phenotypic screening and significantly improve introgression of E. arundinaceus into sugarcane.

References


WORLD REFERENCE IN TECHNOLOGY FOR THE PRODUCTION OF SUGAR, ETHANOL AND ENERGY

28th to 31th August
Sertãozinho - SP - Brazil
Centro de Eventos Zanini
Identification of intergeneric hybrids between *Erianthus arundinaceus* and *Saccharum spontaneum* through STMS markers


Biosecurity against invasive alien insect pests: A case study of Chilo sacchariphagus (Lepidoptera: Crambidae) in the southern African region†

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abstract

The spotted stemborer Chilo sacchariphagus poses a major constraint to sugar production in Mozambique. Current management strategies, in combination with resistant varieties and classical and augmentative biological control tactics, have the potential to combat this serious pest. However, C. sacchariphagus poses a major biosecurity risk to surrounding sugar producing countries in southern Africa. In response to this threat, a comprehensive awareness campaign has been rolled out. It comprises dissemination of illustrative posters, convening of mini-workshops for role players to review phytosanitary measures and regulations, and provision of information on monitoring for the presence of this pest in an attempt to prevent further range expansion. Despite implementing these strategies, there has been limited success in preventing the spread of C. sacchariphagus within Mozambique. This has highlighted the importance of developing a more aggressive biosecurity strategy. In response, a comprehensive incursion plan has been developed for this pest, and the need for increased engagement of relevant policy-making bodies within this region to streamline legislation and enforcement thereof has been identified. In the longer term, the initiation of research on biosecurity and development of a research presence in an area-wide integrated pest management plan is proposed. This paper documents the successes to date of the C. sacchariphagus regional biosecurity programme driven by SASRI and sets out a proposed future action plan.

Keywords: biosecurity, Chilo sacchariphagus, incursion plans, invasive species, southern African region, sugarcane borer

Bioseguridad contra especies foráneas de insectos plaga: Estudio del caso de Chilo sacchariphagus (Lepidoptera: Crambidae) en la región sur de África

El barrenador moteado del tallo Chilo sacchariphagus plantea una dificultad principal para la producción de azúcar en Mozambique. Las estrategias actuales de manejo, en combinación con variedades resistentes y tácticas mejoradas de control biológico tienen el potencial para combatir esta importante peste. No obstante, Chilo sacchariphagus plantea un riesgo principal de bioseguridad para los países productores de azúcar del entorno, en el sur de África. En respuesta a esta amenaza se ha desarrollado una amplia campaña de concientización. Comprende la distribución de carteles ilustrativos, la reunión de mini talleres de interesados para revisar las medidas y regulaciones fitosanitarias y la provisión de información sobre el monitoreo de la presencia de esta peste, en una tentativa para prevenir una expansión ulterior de su rango. Pese a la implementación de estas estrategias ha habido un éxito limitado en la prevención de la dispersión de C. sacchariphagus dentro de Mozambique. Esto ha destacado la importancia de desarrollar una estrategia de bioseguridad más agresiva. Como respuesta se ha desarrollado un plan comprensivo de ataque para esta peste, y se ha identificado la necesidad de un aumento del compromiso de los organismos relevantes de decisión política en esta región a fin de perfilar la legislación y su ejecución. En el plazo largo es necesario iniciar la investigación en bioseguridad y el desarrollo de una presencia de la investigación en Mozambique, con la financiación de los países del SADC en caso de ser necesario. Esto debería incluir un programa de cría de plantas a fin de desarrollar variedades de caña de azúcar resistentes a C. sacchariphagus e investigación en tácticas de control como la Técnica de Insecto Estéril (SIT) y la perturbación de aparejo. Se propone la integración de estas técnicas con el biocontrol clásico y aumentado y otras opciones de control más convencionales en un plan de manejo integrado de plagas para toda el área. Este trabajo documenta los éxitos hasta el momento del programa de bioseguridad regional de C. sacchariphagus conducido por el SASRI y establece una propuesta para un futuro plan de acción.

Biosegureança contra pragas de inseto exóticas invasoras: Um estudo de caso do Chilo sacchariphagus (Lepidoptera: Crambidae) na África Austral

A broca manchada Chilo sacchariphagus coloca uma restrição importante para a produção de açúcar em Moçambique. Estratégias de gestão...
Introduction

The problem of invasive alien species continues to pose challenges to agriculture, government, and the community as a whole. Increased trade and global climate change are some factors making it easier for pests and diseases to spread and establish in previously unaffected areas. Market expansion has increased exchange of contaminated plant material between countries and the numbers of ‘stowaways’ has increased due to an increase in air traffic. Alien, or naturally occurring phytophagous insects that invade commercially important agricultural crops are detrimental because of the cost of control and because they may prevent export programmes or cause significant ecological disturbance which results in loss of biodiversity (Westphal et al., 2008).

Global dependence on monocultures of a few crop species has reduced the resilience of agricultural systems to biological invasions. Therefore biosecurity programmes have become critical. These programmes serve to make stakeholders aware of any potential invasive pest or disease problem, and make provision for appropriate structures and mechanisms to handle these invasions. Biosecurity incursion plans have been developed for many agricultural crops in different countries, a good example is the implementation of incursion plans for sugarcane in Australia (Sallam and Allsopp, 2008). These provide a way to respond timely and appropriately to any new invasion by documenting key operational guidelines and activities, and technical tools and procedures, which underpin the necessary decision-making process and subsequent implementation. Coordinated partnerships, at local, national, regional and international level, allow close and frequent collaboration between relevant phytosanitary agencies and involved agencies towards developing and enforcing appropriate policies and procedures.

One of the current major risks to the sugarcane industry in southern Africa is the threat of invasion by the spotted stemborer Chilo sacchariphagus Bojer (Lepidoptera: Crambidae) from Mozambique. The consequence of this pest extending its range through deliberate or inadvertent movement of sugarcane material from one part of Mozambique to another, or across borders into other sugar industries in the southern African region, would be dire.

The South African Sugarcane Research Institute (SASRI) is driving a C. sacchariphagus biosecurity programme to address this potential threat. After presenting the pest and the current situation, this paper documents the actions that have been taken in response, with recommendations for additional initiatives.

Knowledge base

C. sacchariphagus is oriental in origin, and has spread west across the globe into many sugar industries including Mauritius and Reunion (Williams, 1983) and, since 1998, Mozambique (Way and Turner, 1999). This stemborer has been a major constraint on sugar production in Mozambique. Since 2000, Mozambique (Mafambisse) estate and Companhia de Sena (Marromeu or Sena) sugar estates. Infections at Mafambisse, where damage appears to increase during below-average rainfall seasons, have generally increased each year, which is partly attributable to changes in variety disposition. The other two main sugar estates in the south part of Mozambique, namely Maragra situated in the southern Mozambican district and Açucaireira de Xinañave (Xinavane) state, have never been invaded by C. sacchariphagus. Stem boring damage caused by C. sacchariphagus larvae leads to substantial loss (Goebel and Way, 2009). This borer is restricted largely to sugarcane, with a few unsubstantiated other host records (Williams, 1983). Despite the presence of the natural enemies preying on all life stages in infested crops, populations are frequently insufficiently controlled (Conlong, 2000; Conlong and Goebel, 2002).

Invasion of South African sugarcane

So far, C. sacchariphagus has not invaded South Africa, but climatic suitability studies show that the KwaZulu-Natal coastline of South Africa and adjacent deep river valleys, especially in the north, are the most vulnerable parts to its establishment in the region (Goebel, 2006; Bezuidenhout et al., 2008). Escape from specialist natural enemies is a further factor favouring the establishment of this exotic pest in South Africa. Management options in the areas of origin comprise a combination of planting clean seedcane, hot water treatment (HWT) of seed cane at 50°C for 30 minutes, annual harvest, resistant varieties and releases of natural enemies.
Research completed in Mozambique

A concerted control effort employing multiple tactics arguably has the potential to eradicate C. sacchariphagus from Mozambique. Managing the insect through classical and augmentative biological control within an integrated pest management (IPM) plan is also an option. For example in 2001, Xanthopimpla stemmator Thunberg (Hymenoptera: Ichneumonidae) was released in Mozambican sugarcane, and within a year 60% reductions of C. sacchariphagus populations were measured, with parasitoid recoveries two years after releases ended (Conlong and Goebel, 2002). An effective indigenous egg parasitoid, Trichogramma bournieri Pintureau and Babault (Hymenoptera: Trichogrammatidae), is present in sugarcane in Mozambique (Conlong and Goebel, 2006). Differences in relative varietal resistances have been found (Conlong et al. 2004) and older carry-over crops reportedly support higher C. sacchariphagus infestations.

Monitoring options available

Natural spread of this stem borer from Mozambique is unlikely, because the sugar estates are remote and are surrounded by natural vegetation, across which these moths are unlikely to fly. However, moving sugarcane material infested by C. sacchariphagus from the source location poses a serious problem due to recent expansions and traffic between sugar industries. Border towns such as Komatipoort in South Africa are probable high risk entry points, and transport in this instance will be primarily by private vehicles that do not get adequately inspected for plant material. The situation is further exacerbated by the fact that travelers naively, or deliberately, frequently bring across the border fresh sugarcane stalks that might be infested.

C. sacchariphagus distribution is monitored using trapping systems employing pheromone lures (Nesbitt et al., 1980) to attract individuals into the trapping device. A grid of traps has been deployed along a strategically important area with the view of using this surveillance to increase the likelihood of detecting the pest should it invade South Africa. It is important to note in this regard that eradication cost is directly proportional to the period between invasion and detection (latent period) of any pest species; hence the importance of establishing such intensive surveillance systems. Once detected, the communication networks among relevant role players, organisations and bodies, including farmers, crop protection workers, industry managers, government and agricultural policy makers, are used to report an invasion.

Visual scouting is also used to search for stem borer damage symptoms, which are shot holes on leaves and side-shooting of stalks. It is important to positively identify any specimens found in the field due to possible confusion with the maize stemborer C. partellus (Swinho) (Lepidoptera: Pyralidae) (Way and Kfir, 1997).

Scouting and trapping monitoring techniques have been used to determine the presence of C. sacchariphagus at Mafambisse and Sena (Way and Turner, 1999, Conlong, 2000). Field visits have shown that this species is absent from the southern estates in Mozambique (Way and Goebel, 2003), Malawi (Rutherford and Way, 2003), Swaziland (Way and Kfir, 1997) and Massingir in Mozambique (Way and Erasmus, 2009).

Development of an incursion plan

Since 1999, SASRI has driven a regional biosecurity programme between and within SADC countries that includes all biological threats, including the immediate threat from C. sacchariphagus. Dedicated biosecurity workshops have been organised in South Africa (Mpumalanga Province), Swaziland and Mozambique. These workshops have raised awareness about pest threats, highlighted tools (revised C. sacchariphagus poster), discussed scouting and the refined trapping technique, and reviewed C. sacchariphagus control tactics and future research projects, including the need for a balanced variety disposition to reduce the pest risk, with emphasis on the C. sacchariphagus susceptible variety N25.

Shortcomings

Resilience to imminent incursions may be achieved by developing phytosanitary regulations and associated legislation for enforcement, effective surveillance systems to allow rapid detection, awareness propaganda about potential incursions, and contingency incursion plans as a means to respond timeously and appropriately to any new invasion. Although these actions will certainly reduce the risk of pest threat, unfortunately, recent observations in Mozambique (Way, 2010) have shown that, despite the best efforts by SASRI to contain this pest, C. sacchariphagus has spread out of the delimitation zone in Mozambique, and it thus poses a greater biosecurity threat than previously. The response to this development has been to alter the focus of the C. sacchariphagus biosecurity plan by placing more emphasis on the need to control the pest at its source in Mozambique. The spread of the pest within Mozambique has clearly illustrated the need for more stringent control on the sugarcane estates at the source in Mozambique.

New biosecurity initiative

Following the successes and shortcomings experienced with the C. sacchariphagus biosecurity programme, a revised and more direct approach has been used to strongly promote legislative processes because the recommendations are invariably not being adhered to. Some of the following recommendations are:

- There is a need for the National Department of Agriculture in South Africa (NDA) to declare C. sacchariphagus a quarantine pest. This will allow control measures to be applied throughout South Africa.
- Movement of all sugarcane material across the border between Mozambique and South Africa needs to be prohibited. Further engagement with the NDA is required to review the policy document that allows a limited number of sugarcane stalks to be transported from Mozambique through the Komatipoort border post into South Africa.
- Phytosanitary cross border control between South Africa and Mozambique requires attention which can be improved through engagement between the South African Sugar Association (SASA) executive and the NDA.
- To achieve the goals of the C. sacchariphagus biosecurity programme crop protection, workers in South Africa need to...
continue visiting Mozambique fields for borer inspections.
- The *C. sacchariphagus* awareness programme needs to be promoted by the SASRI Extension Officers and Local Pest, Disease and Variety Control Committee (LPD&VCC) officers in strategic regions close to the border with Mozambique (Mpumalanga, Pongola) in South Africa.
- Continued collaboration is required between specialist researchers (entomologists and pathologists) from SASRI, administrative staff from SASRI including the Director of the Institute, the recently appointed Biorisk Manager and the Knowledge Manager, field managers and senior policy makers from the major sugar producing companies in Mozambique.
- The Local Pest, Disease and Variety Control Committee (LPD&VCC) need to clarify rules pertaining to financial compensation to growers issued with plough-out orders due to newly emerging hazardous pests or diseases in South Africa.
- Associação dos Produtores de Açúcar de Moçambique (APAMO) should be approached with a framework document detailing strategy, local infrastructure, networking systems, research priorities, individual, corporate and government responsibility, phytosanitary regulations and compliance therewith. Engagement with APAMO on issues of infrastructure in Mozambique developed to regulate the phytosanitary component of agricultural activities is required. There is a need to determine which parties or bodies are responsible for regulating seedcane movement in Mozambique.
- There should be a moratorium on moving material from the northern sugar estates (Sena and Mafambisse) to the southern ones (Xinavane and Maragra). The possible introduction of a ‘cordon sanitaire’ around the infested sugar estates, possibly using the Zambezi River in the north and the Save River in the south, requires urgent consideration.
- Action must be taken to degazette the susceptible variety N25 in Mozambique.
- Continued and more aggressive communication is needed to inform the Mozambique authorities about the risk posed by this borer. Engagement between affected countries and the relevant policy-making bodies that are responsible for regulating seedcane movement.

**Development of regional biosecurity research centre in area of invasion**

Another facet of the new biosecurity initiative revolves around increasing the ability to control the pest in the areas of origin in Mozambique, which in turn will restrict range expansion within Mozambique and further afield and automatically reduce the level of this pest threat in the southern African region. The following recommendations set out by SASRI need to be adopted with a minimum of delay:

- Only clean seed that is not infested with *C. sacchariphagus* must be used for new estate plantings.
- Where necessary, seedcane schemes such as those operating in South Africa with hot water treatment (HWT) at 50°C for 30 minutes must be established.
- Where possible, the area planted to the *C. sacchariphagus* susceptible N25 variety (Conlong et al., 2004) should be limited, and a balanced variety disposition with less than 30% per variety is recommended.
- Carry-over cane must be avoided since infestations cannot be easily controlled in crops older than 12 months.

The following longer term recommendations need to be pursued:

- Overall, a more concerted IPM approach combined with research and implementation of novel insect control tactics in the longer term needs to be implemented.
- A programme for breeding *C. sacchariphagus* resistant varieties is warranted. Such an initiative would have to be established and staffed on estates in Mozambique. SASRI could then provide released, pre-release and parental genotype material (Nibouche and Tibère, 2008). Consideration should be given to the export and planting of tissue cultured material (Anon, 2009).
- Additional biological control options that require research include augmenting populations of the egg parasitoid *Trichogramma bournieri* Pintureau and Babault (Hymenoptera: Trichogrammatidae).
- The monitoring programme needs to be extended, with vigilance and monitoring on Malawi sugar estates that, being immediately across the Zambezi River, are at high risk of invasion by *C. sacchariphagus* from Sena Sugar Estate in Mozambique.
- To assess the effectiveness of control measures and also the current status of this pest, there is a need for regular scouting programmes in infested fields on sugar estates in Mozambique and on estates in Mozambique where the pest has not been recorded.
- The *C. sacchariphagus* scouting and trapping programme needs to be sustained and moreover extended to cover a larger area within the southern African region. The surveillance systems along the South African/Mozambique border should be increased, with permanent monitoring using pheromone-baited traps along the Malawi/Mozambique and Mozambique/Makatini Flats corridors.
- Sterile Insect Technique (SIT) and mating disruption are novel control tactics that could be researched in Mozambique. The mating disruption technique involves saturating sugarcane crops with a synthetic form of the scent (pheromone) released by moths to attract mates; this will disrupt normal functioning of communication which in turn will reduce numbers of fertile eggs laid by females. SIT involves irradiating moths with sub-lethal doses of radiation or x-rays and releasing these individuals into the field to mate with the wild moths, resulting in sterile offspring. These are complementary techniques particularly appropriate for use in Mozambique where, because sugar estates are surrounded by natural vegetation and since the pest apparently only feeds on sugarcane plants, there is no re-infestation from surrounding vegetation.
- It is important to conduct surveys in wild host plants in Mozambique to confirm the host specificity of *C. sacchariphagus*.
- There is value in determining the economic loss caused by *C. sacchariphagus* in Mozambique so that cost-benefit evaluations are possible for any control measures implemented.
• A regional C. sacchariphagus research initiative in Mozambique that is being promoted by SASRI researchers could establish variety screening trials, conduct mating disruption trials, assess parasitoids and monitor pest levels and movement. This regional initiative would need to consolidate collaboration between relevant networks of people in the SADC region towards a coordinated and co-funded biosecurity programme that could deal with any future biosecurity threat facing the region as a whole.
• Inter-industry contact needs to be maintained through mini-workshops and relevant forums to disseminate information about the status of C. sacchariphagus in the region.
• Finally, the biosecurity programme needs periodical review in order to match objectives, needs, capacity and goals.

Conclusion

SASRI, recognising the significance of this particular pest threat, has taken a leading role in the development and implementation of a regional biosecurity programme. The approach has been to control the pest in the area of origin while reducing the chance of range expansion through raising awareness levels. Despite these actions, the stemborer has increased its range in Mozambique and thereby the level of risk in the southern African region. This has necessitated a re-focus with more emphasis on the control of the pest in Mozambique, requiring the development of a regional biosecurity initiative in that country.

Building resilience in neighbouring sugar industries remains important through a greater degree of adherence to phytosanitary regulations and enforcement in Mozambique and across country borders.

Additional mobilisation of working collaborative alliances with regulatory personnel in the SADC sugarcane countries is needed, as are further and ongoing implementation of additional comprehensive public information programmes, education and training of specialist pest diagnostic systems, pest interception programmes, pest eradication programmes and management. Greater coordination of existing infrastructure by the recently established collaborative alliances will strengthen capacity building in the arena of biosecurity within the southern African region.

This paper was presented at the 2011 SASTA annual conference and is published here with the agreement of the Society.

References

Anon (2009) NovaCane® Planting Guide. Published by the South African Sugarcane Research Institute, Mount Edgecombe, South Africa.


Meetings Calendar

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Sugar Asia Conference
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Fax: +91 11 4153 6991
Email: sugarasia@nexengroup.in
www.sugarasia.net

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www.biofuelscee.agraevents.com

20-22 June 2012
Annual Joint Meeting of the American Society of Sugar Cane Technologists
- St. Pete Beach, Florida, USA
Contact: Freddie Martin
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www.assct.org

25-27 June 2012
SIMTEC: International Symposium and Technology Exhibition on the Sugar & Ethanol Industry
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www.sugaralliance.org/symposium

15-17 August 2011
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www.sasta.co.za

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