SRDC Research Project
Final Report

Cover Page:

Title of the Project: **Pre-treatment of sugar cane**

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A statement of confidentiality (if applicable):

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Body of the Report:

Executive Summary:

This project developed a customised microwave applicator for the pre-treatment of sugar cane. Three undergraduate Engineering students investigated the optimisation of microwave treatment, mechanical and chemical properties. The microwave treatment resulted steam, popping or burning of the sugar cane depending on the power and treatment time. The investigations substantiated that the microwave treatment of the sugar cane soften the strength of the sugar cane. Young's modulus, yield strength and ultimate strength in compressive state were measured as functions of different microwave-treatment parameters. Results have demonstrated that microwave treatment has resulted in up to an 80% reduction in cane billet mechanical properties including yield strength, ultimate strength, and Young's modulus. Microwave treatment significantly reduced the compressive strength of sugar cane making it easier to crush and as result around 60% energy can be saved during the crushing process.

Experiments were conducted to find the time required to reach equilibrium, which is assumed when the brix% has not changed in a period of 30 minutes. Colour, purity, corrected brix, corrected pol and CCS were then determined in duplicate for each sample at the South Johnstone Sugar Mill (SJSM) laboratory. The results from the SJSM laboratory analysis shows that there is little difference between the two microwave treatment conditions tested in terms of final Colour, purity, corrected brix, corrected pol and CCS. For all three variables the p-Value is greater than 0.05, this is evidence to accept the null hypothesis suggesting that differences between the two microwave conditions are statistically insignificant. This study confirmed that 5 minutes of microwave treatment has no statistically significant impact on any of the key variables that determine the quality of sugar cane juice. Therefore there is no potential consequence in using microwave to pre-treatment the sugar cane before crushing by industry.

Issue:

Cane shredding is required to increase the percentage of open cells (POC) in cane billets and thus enable extraction of sucrose in the milling process. Shredding accounts for approximately 30% of the total power requirement of a sugar mill, which translates into significant amounts of energy usage across Australian sugar mills. Even minor reductions in this component of the energy budget would contribute to increased efficiency and profitability of the sugar extraction process.

Previous research undertaken (such as the CRC for wood and preliminary work in sugarcane) indicates that microwave pre-treatment will

- rupture the internal cellular structure of cane, reducing the power requirements of cane shredders. Given that shredding accounts for approximately 30% of a sugar mill's total power requirements, significant benefits may accrue
- increase the extraction efficiency of sucrose, given the resulting increase in the percent open cell (POC) of prepared cane

The project aimed to develop strategies for the future development of large scale applicators.

R&D Methodology:

Under the guidance of project leaders from James Cook University and the University of Melbourne, who possess expertise in the areas of microwave, process and mechanical

engineering, three high calibre, 4th year Engineering Honours students will carry out laboratory-based scoping studies in the following areas:

- An electrical engineering student will design and construct a test system for high intensity microwave pre-treatment of sugar cane billets.
- A mechanical engineering student will evaluate the mechanical and microscopic structural properties of the treated cane to determine the power requirements for shredding microwave-treated cane.
- A chemical engineering student will carry out an experimental program evaluating improvements to the diffusion process associated with microwave-treatment cane. This study will also evaluate any deleterious effects, in terms of sucrose losses, that may occur.

Outputs:

Three undergraduate students completed their thesis analysing the Electrical/ Energy requirements, Mechanical and Chemical properties.

Both the Electrical and Mechanical thesis students demonstrated the softening of the sugar cane and energy savings especially during crushing.

The Chemical Engineering data showed no changes in the quality of the sugar.

Our calculations show a 60% energy reduction to crush the sugar cane. This will have a significant impact on the sugar industry and sugar growers as the burning of bagasse as a fuel is a green house positive process (approx 0.54522kg CO_2 sequestered per 1KW of energy used: [reference www.carbontrust.co.uk]).

All the collected data as part of the thesis is shown in the appendix of the thesis documents (already submitted to SRDC).

Impact:

Diffusion testing has confirmed that the quality of juice extracted after microwave treatment is largely unaltered. This indicates that microwave treatment would not have a detrimental effect on the cane payment system used for growers and millers.

The cane shredder accounts for approximately 30% of the total energy requirements in a sugar mill. Shredder hammers also wear quickly and need to be regularly replaced. Any reduction in shredder energy requirements will improve sugar processing energy requirements and softening of cane will reduce maintenance demands. Studies show that intense microwave energy can: significantly reduce energy requirements for wood pulping; and soften wood polymers. This work has shown softening of cane as a result of microwave treatment.

Implantation of the developed technology in conjunction with a sugar mill will assist to reduce the amount of electricity needed for processing and thereby maximise the available bagasse for energy co-generation. This will have a significant impact on the sugar industry and sugar growers as the burning of bagasse as a fuel is a green house positive process.

Background:

The sugar industry generates more than 40,000 jobs in Australia and sugar is the second largest export crop in Australia with total annual revenue worth around $2 billion. In 2002, more than 38 million tonnes of cane was crushed and 5.25 million tonnes of raw sugar was produced. About 80 to 85 % of raw sugar is exported.

Sugar mills which extract as much sucrose from the cane stalk as possible represent a substantial investment by the industry and therefore influence the overall economic viability of the industry.

Mechanical shredders, usually employing rotating knife blades, are used to rupture the storage parenchyma cells in the pith to allow easy extraction of the cane juice through the crushers. The chopper and shredder accounted for almost 50% of the total power requirements for the juice extraction train in a sugar mill with 4 crushers. In terms of overall energy requirements for the whole sugar production process in a mill, the cane shredder accounts for approximately 20% of the total energy balance in entire sugar mill. Clearly, reductions in the energy requirements of the cane shredder could provide significant economic benefits to the industry. Any reduction in the mechanical strength of the sugar cane (softening the cane) will substantially reduce the energy required in the shredding phase of sugar production.

It has been demonstrated that the controlled application of intense microwave energy to green timber can directly manipulate moisture permeability, wood density and wood strength by rupturing cells without the need to use steam and long processing times. The change in density associated with microwave treatment can significantly reduce the hardness of plant materials. This project was formulated based on the assumption that the reductions in material density, hardness and energy requirements can be achieved by using microwave energy to precondition sugarcane. It is anticipated that there should be a corresponding reduction in processing costs associated with preparing cane for crushing and a reduction in ware on shredder blades.

Objectives:

Objective #1:

- Design and construction of a suitable microwave treatment system that can be used for small scale treatment of sugar cane billets.

It will investigate appropriate treatment protocols and demonstrate “proof of concept”. This phase will also identify key design and safety features that can be used to develop a “pilot scale” system for future research and demonstration to the industry.

Objective #2:

- Perform mechanical and microscopic tests on the microwave treated cane billets to quantify the degree of structural modification achieved by microwave pre-treatment.

This data can be used to quantify the potential energy savings that can be achieved using microwave pre-treatment in the milling chain using a variety of testing methods, including the tensile strength of treated fibres.

Objective #3:

- Extraction tests that will be used to quantify the improvements or losses Sucrose during sucrose extraction after cane billets have been microwave pre-treated.

The project is largely a consolidation stage, in which all of the results will be collected together and an overall evaluation of the project will be made. A measure of the reduction/addition of energy in kilowatts/tonne of sugar cane will be estimated, although optimisation of the microwave process is required to accurately quantify the reduction. This determination will be complimented with an analysis of the other potential benefits of microwave pre-treatment, largely due to improved extraction efficiency.

Methodology:

- We have procured a conventional domestic microwave oven. We also procured a high power microwave source and fabricated a customised microwave applicator. This applicator can be used to treat sugar cane with microwave with the aid of a waveguide. A water-load was applied in conjunction with the applicator to absorb excess/ leak microwave energy. Enough precautions

were made to make sure that there will not be any leaks. From time to time tests were carried out to measure leakage energy (if there is any) using a microwave detector.

- Several experiments were conducted to identify the correct level of microwave power to be applied. From the preliminary tests it was observed that by varying the duration of microwave treatment steam, popping and burning occurs for fresh sugar cane samples as illustrated below.

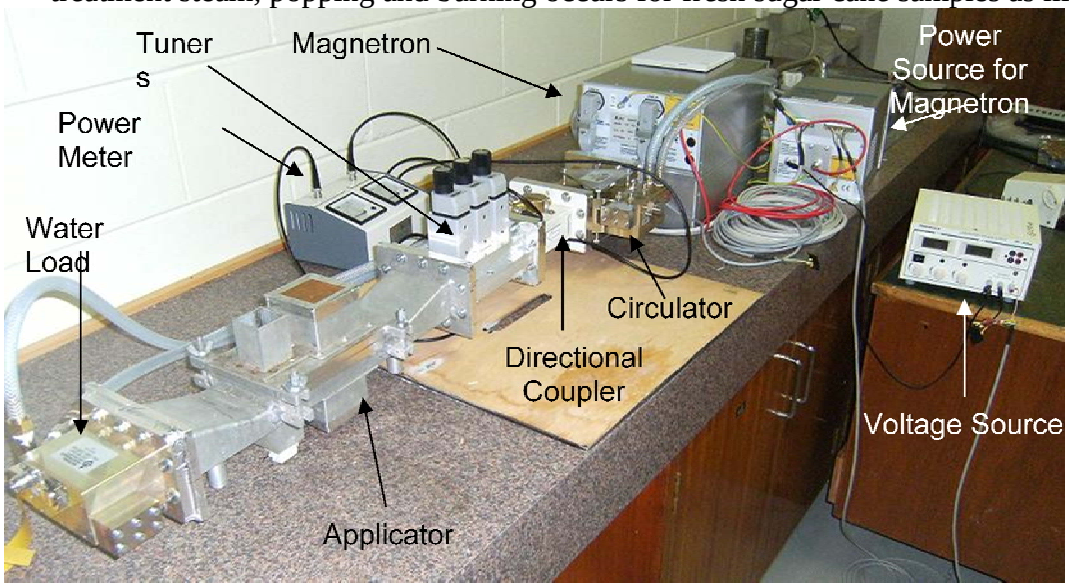

Figure: 1.2 kW Wave-Guide Microwave Applicator

- **Table: Microwave Treatment Observations**

	Conventional Microwave Oven (1.1 kW)	Microwave Applicator (1 kW)
Steam	15 seconds	10 seconds
Popping	70 seconds	30 seconds
Burning	150 seconds	60 seconds

- The conditions such as steam / burning depend not only on time but also on the dimensions of the sample and the moisture content. The table above gives approximate values of when the samples seamed to reach a different point and should only be used as estimate for when these events occur.

- Table below shows different treatment times (using Microwave Applicator) used in the experiment.

Treatment Power (W)	300	300	300	700	700	700	1000	1000	1000
Treatment Time (s)	20	40	60	20	40	60	20	40	60

- Table below shows different treatment times (conventional microwave oven) used in the experiment.

Treatment Power (W)	300	300	300	700	700	700	1000	1000	1000
Treatment Time (s)	30	90	150	30	90	150	30	90	150

The cane was exposed to high microwave energy as above and the samples were used to understand changes in the Mechanical, Chemical and Electrical properties.

Outputs:

Mechanical Properties:

Sugarcane milling and crushing is a major and high-energy consuming process in sugar production. As sugarcane strength increases, crushing forces, torque, specific energy, and crushing temperature increase. For the sake of energy saving in sugar production, we hypothesize that microwave heating to sugarcane as pretreatment can be used to soften sugarcane. To examine our hypotheses, we have conducted our initial investigation of the influences of microwave heating on mechanical properties and microstructure of inter-node sugarcane using universal mechanical testing, laser confocal scanning microscopy and electron scanning microscopy. Young's modulus, yield strength and ultimate strength in compressive state were measured as functions of different microwave-treatment parameters. Results have demonstrated that microwave treatment has resulted in up to an 80% reduction in cane billet mechanical properties including yield strength, ultimate strength, and Young's modulus. There were also several microstructure changes observed in the rind and pith using laser confocal scanning microscopy and scanning electron microscopy.

Mechanical shredders rupture the storage parenchyma cells in sugar cane stalks to facilitate extraction of the cane juice during milling. The cane shredder accounts for approximately 30% of the total energy requirements in a sugar mill. Shredder hammers also wear quickly and need to be regularly replaced. Any reduction in shredder energy requirements will improve sugar processing energetics. Studies show that intense microwave energy can: significantly reduce energy requirements for wood pulping; and soften wood polymers. Individual sugar cane billets were treated with microwave energy and tested for compressions strength using an Instron 1342 mechanical testing machine. Microwave treatment significantly reduced the compressive strength of sugar cane making it easier to crush. Microscopic examination of the cane using a laser conformal microscope revealed significant structural modification to the cane cells. These modifications and glassification of the woody polymers by the microwave energy contributed to this reduction in compressive strength.

Diffusion Experiments

*(*Details on the analysis methods used at the SJSM laboratory can be found in Appendix)

Experiments were conducted to find the time required to reach equilibrium. This was considered to be when the brix% had not changed in a period of 30minutes. The brix% was measured every 10 minutes with an Atago PR101 bench top refractometer and three measurements were taken to obtain an average at each sample time.

After the time required for equilibrium had been determined 5 repeats were conducted for both no treatment and 5 minute treatment conditions. The samples were strained and left for at least two hours to reach room temperature so the pH could be measured. Once the pH was measured the juice was poured in 0.5L sample bottles which had approximately 3mL of formaldehyde added and were then frozen to prevent bacteria growth. Colour, purity, corrected brix, corrected pol and CCS were then determined in duplicate for each sample at the South Johnstone Sugar Mill (SJSM) laboratory.

The results from the experiments shows that the no treatment condition reaches equilibrium after 150 minutes at a final brix% of 7.2 whereas the 5 minute treatment condition takes 130minutes with a final brix% of 6.4. These results are qualitative because only one preliminary experiment was performed it is difficult to compare the diffusion rates. They are however supported by the work of

Roberts (2010). It is important to note the plant cane harvested for this study was not yet mature and a broader study of cane variety is required.

Our study shows that 5 minutes of microwave treatment removes approximately 1.3% of the total cane mass in water and is at a temperature of 97.56°C after treatment. The treated cane appears to have a slightly more hydrogen ions in solution. The results from the SJSM laboratory analysis shows that there is little difference between the two treatment conditions tested in terms of final Colour, purity, corrected brix, corrected pol and CCS. To confirm this, a t-test was performed on the data in Table 4 using a two tail t-distribution. The conservative approach of assuming unequal variance between the two populations was taken. The null hypothesis tested is that the two microwave treatment conditions are not statistically different using a 95% confidence interval.

For all three variables the p-Value is greater than 0.05, this is evidence to accept the null hypothesis suggesting that differences between the two microwave conditions are statistically insignificant. This study demonstrated that 5 minutes of microwave treatment has no statistically significant impact on any of the key variables that determine the quality of sugar cane juice, which is a significant hurdle needed to be overcome to ensure adoption by industry.

Table 1: Results from the SJSM laboratory analysis for Colour, Purity and CCS.

	No treatment			**5 minute treatment**		
	Colour	Purity	CCS	Colour	Purity	CCS
	53	78.96	4.16	55	77.43	3.86
	49	83.11	4.24	55	76.4	3.81
	38	79.74	4.17	53	81.71	4.35
	37	81.73	4.30	56	73.78	3.89
	44	81.97	4.38	44	78.67	4.02
	40	83.07	4.42	46	78.4	4.00
	49	76.8	3.70	47	88.47	4.71
	46	79.43	3.82	46	86.81	4.38
	48	74.58	2.87	48	82.5	3.96
	49	75.86	2.91	47	82.94	4.00
Average ± 95% confidence	**45.3±3.33**	**79.53±1.87**	**3.897±0.36**	**49.7±2.80**	**80.71±2.87**	**4.098±0.18**

Table 2: The pH of sugar juice for both no treatment and 5 minute treatment conditions.

	pH	
	No Treatment	**5 minute Treatment**
	5.41	5.3
	5.43	5.4
	5.4	5.22
	5.31	5.2
	5.2	5.28
Average ± 95% confidence	**5.35±0.08**	**5.28±0.07**

A t-Test assuming unequal variance with a 95% confidence interval demonstrated that 5 minutes of microwave treatment has no statistically significant impact on any of the key variables that determine the quality of sugar cane juice.

Table 3: p-Values obtained from a t-Test assuming unequal variance with a 95% confidence interval.

Variable	**p-Value**
Colour	0.064
Juice Purity	0.508
CCS	0.340

Economic Benefits Analysis:

Microwave treatment significantly reduced the compressive strength of sugar cane making it easier to crush and as result around 60% energy can be saved during the crushing process. The cane shredder accounts for 30% of the total energy consumed by sugar mill. This means that the microwave pre-treatment could save 18% of the energy consumed by the mill.

Intellectual Property and Confidentiality:

The investigation substantiated for the first time that microwave pre-treatment of sugar cane decreased the strength of materials and thereby significant reduction in the energy required to crush the cane. We haven't lodged a patent since more work is needed to understand the feasibility of implementing the technology in conjunction with the sugar mill, which will be the subject of a future research project.

Environmental and Social Impacts:
(Including any expected or actual adverse or beneficial environmental or social impacts of conducting the project and/or implementing its findings)

Diffusion testing has confirmed that the quality of juice extracted after microwave treatment is largely unaltered. This indicates that microwave treatment would not have a detrimental effect on the cane payment system used for growers and millers.

The cane shredder accounts for approximately 30% of the total energy requirements in a sugar mill. Shredder hammers also wear quickly and need to be regularly replaced. Any reduction in shredder energy requirements will improve sugar processing energy requirements and softening of cane will reduce maintenance demands. Studies show that intense microwave energy can: significantly reduce energy requirements for wood pulping; and soften wood polymers. This work has shown softening of cane as a result of microwave treatment.

Implantation of the developed technology in conjunction with a sugar mill will assist to reduce the amount of electricity needed for processing and thereby maximise the available bagasse for energy co-generation. This will have a significant impact on the sugar industry and sugar growers as the burning of bagasse as a fuel is a green house positive process.

Expected Outcomes:

- Three undergraduate students completed their thesis analysing the Electrical/ Energy requirements, Mechanical and Chemical properties.
- Both the Electrical and Mechanical thesis students demonstrated the softening of the sugar cane and energy savings especially during crushing.
- The Chemical Engineering data showed no changes in the quality of the sugar.

- Our calculations show a 60% energy reduction to crush the sugar cane. This will have a significant impact on the sugar industry and sugar growers as the burning of bagasse as a fuel is a green house positive process.
- All the collected data as part of the thesis is shown in the appendix of the thesis documents (already submitted to SRDC).
- The project substantiated the potential benefits of microwave pre-treatment of sugar cane. In order to apply this in conjunction with a mill, a 500 KW microwave system can be adopted, which could heat the sugar cane at approximately 500 tonnes/ hr. The cost to run such system is around $10/ tonne. The proposed system is similar to the "microwave wood processing unit" available at University of Melbourne: (http://www.microwavewoodprocessing.com/Videos/videodemonstration.wmv)

Future Research Needs:

It is essential to study the feasibility of implementing the technology in conjunction with the sugar mill. Towards a full scale study and analysis we need 2 research assistant (one in instrumentation and the other in Chemical analysis). We will be seeking funding to do an industry based research, which will include a detailed financial analysis, prior to promoting the developed technology.

We will also continue research on the influence microwaves on the node sections and will compare with the data that we obtained for internodes.

An international PhD student has been accepted to begin a research thesis in late 2011. The subject off his research is to investigate changes in material (rind) characteristics resulting from microwave treatment, optimising microwave intensity and undertaking an analysis of the impacts of treatment on industry milling (economics and environment) by utilising an lab scale mill. Macknade mill in Ingham have expressed a willingness to collaborate and supply related industry data for this purpose. This project will require project funds for experimental apparatus and analytical testing and a scholarship will allow the student to dedicate sufficient focus on their studies as well a facilitate dissemination of their project outcomes.

Recommendations:

In summary we have substantiated that microwave treatment can substantially reduce the power required to crush the cane without compromising the quality of sugar. Therefore we would like to pursue more research in this area especially in conjunction with a sugar mill.

List of Publications:

1) Graham Brodie, Mohan V Jacob, Madoc Sheehan, Ling Yin, Megan Cushion, Gerard Harris,, "Microwave Modification of Sugar Cane to Enhance Juice Extraction During Milling", Proc Aust Soc Sugar Cane Technol Vol 33 2011 (paper attached)

2) Graham Brodie, Mohan Jacob, Madoc Sheehan, Ling Yin and Gerard Harris, Effect of microwave treatment on the extraction of sugar juice from cane, accepted for presentation in PACRIM-9, Cairns July 10-15, 2011 and full paper to be submitted to the Journal of the Microwave Power and Electromagnetic Energy