THE EFFECT OF ADDED WATER TEMPERATURE ON MILLING TRAIN OPERATION AND PERFORMANCE

By

G.A. KENT

Queensland University of Technology, Brisbane, Australia
g.kent@qut.edu.au

KEYWORDS: Added Water, Imbibition, Maceration, Milling, Extraction.

Abstract

FOUR recent factory experiments have been conducted to provide information to determine an optimal added water temperature. The results were not completely conclusive but did provide some further insight into the effect of added water temperature. The effect of added water temperature on extraction has proven particularly difficult to measure. There is little doubt that bagasse is more compressible at higher temperature. Two experiments have shown that bagasse moisture content is lower at higher temperature. These effects are most likely related. Two experiments produced indirect evidence of an increase in extraction with higher added water temperature. With bagasse being more compressible, mill capacity is increased at higher temperature. The use of a heat exchanger to cool added water with mixed juice reduces heat loss and consequently reduces steam usage for primary heating of juice. Some of the lost heat may serve a useful purpose in increasing boiler efficiency, resulting in more efficient use of bagasse. Hotter added water does not appear to be a complete solution for mill hygiene since even the hottest added water investigated only provides sufficient benefit for the last one or two mills. There remains considerably more work to identify the optimal added water temperature. The main outstanding issues are the effect of added water temperature on extraction, the effect of hotter bagasse on boiler efficiency through moisture content or temperature and the impact of bagasse temperature on hygiene.

Introduction

According to Maxwell (1932), the optimal temperature for milling train added water has been debated since the nineteenth century (von Czernicky, 1899). Chen (1993) provided a comprehensive list of the arguments with benefits of high temperature being fuel economies, rupture of cells, evaporation from bagasse in transit, use of return condensate from evaporators and a gain in extraction, and disadvantages of high temperature being extraction of gums and impurities, poorer mill feeding and the facilitation of growth of micro-organisms that produce dextran.

Much of the data on which today's understanding of the impact of added water temperature dates back many years. Maxwell (1932) questioned the validity of the results of von Czernicky (1899) since milling technology had changed in the intervening 30 years. Milling technology has continued to evolve, with innovations such as roll roughening, closed feed chutes and automatic control systems. There is a need to reassess conventional wisdom on the subject.

This paper reviews past work, presents recent work and presents a theory to explain the measured impacts.

Definitions

Throughout this paper, *added water* refers to water that is added to the milling train to aid the extraction process. Added water is usually applied before the final mill.

Most past work on the subject uses the terms *maceration* or *imbibition*. Clayton (1971) defines imbibition as *the process in which water or juice is applied to a bagasse to enhance the extraction of juice at the next mill.* This definition includes the above definition of added water but also includes juice added to mills before the final mill. Clayton (1971) indicates that the term maceration is used *loosely as an alternative to the term imbibition*.

Review of past work

Fuel economy

Fuel economy results from a boiler efficiency increase that can be achieved through burning bagasse of lower moisture content. Khainovsky (1929) reported reductions in bagasse moisture content from cold maceration (20°C to 30°C) to hot maceration (80°C to 90°C) processes.

Rupture of cells

Khainovsky (1929) reported that living cells were not ruptured and actively worked to increase their sucrose content. He found that, using cold imbibition, living cells could still be detected in final bagasse. The actual temperature at which living cells were killed was not measured but Khainovsky indicated it was about 60°C.

Ramaiah *et al.* (1979) stated that surface tension effects were responsible for sucrose being trapped in cells. Kumar and Agrawal (2000) stated that hot imbibition reduces surface tension effects, increasing extraction. No supporting evidence was presented.

Evaporation from bagasse in transit

Hotter added water results in hotter bagasse. While it is expected that hotter bagasse will result in greater evaporation, and hence lower moisture content, it is not believed that any such measurements have ever been published.

Use of return condensates from evaporators

Many factories use hot condensates from the evaporators for added water. Valdes *et al.* (1994) presented a study to maximise energy efficiency at different added water temperatures.

In some factories, maceration heaters are used to increase added water temperature. Doss (1986) recommends the addition of steam to imbibition in a process called steam aided imbibition. Other published reports discuss methods to reduce added water temperature. Nigam *et al.* (1990) discuss mixing hot condensate with cold water. Leal *et al.* (1986) and Castellat and Mendoza (1988), as reported by Valdes *et al.* (1994), along with Bhojaraj (1990) and Nandagopal (1991), indicate that using a heat exchanger with mixed juice as a cooling fluid is a more energy-efficient method to reduce added water temperature. Bhojaraj (1990) indicates this method can save 3% steam on cane.

Extraction of sucrose

Khainovsky (1929) reported reductions in bagasse pol content between the use of cold maceration (20°C to 30°C) and hot maceration (80°C to 90°C) processes. Khainovsky noted that hot bagasse was more compressible and indicated that this property was responsible for the improved performance.

From studying extraction results over several seasons, Gonzalez (1953) found no change in extraction after changing added water temperature from 77°C to 55°C.

Sugar Research Institute (1955) found an increase in total pol extraction by increasing added water temperature from 38°C to 77°C. The hot added water tests also involved the addition of steam into the mill boots, resulting in hotter bagasse at the intermediate mills and increased added water rate because of the condensed steam.

Haines and Hughes (1962) found an increase in pol extraction by increasing added water temperature from 26°C to 77°C.

Hugot (1986) reported that, of his four factories, one factory found an improvement in extraction with hot imbibition but the remaining three factories did not.

Ramasamy (1988) conducted factory and laboratory experiments to compare different imbibition temperatures and steam aided imbibition. He found that bagasse pol content was lower with higher temperature imbibition and attributed that lower pol content to sucrose inversion. He presented no evidence that sucrose inversion was the cause of the lower pol content (as opposed to, for example, the compressibility mechanism proposed by Khainovsky (1929).

Extraction of impurities

Honig (1953) carried out a factory experiment to investigate extraction of waxy matter. He carried out 10 pairs of tests with added water temperatures of 28°C and 85°C and concluded that there was no definite proof that added water temperature affected extraction of waxy matter.

Gonzalez (1953) found that sugar filterability was much poorer with an added water temperature of 77°C than with an added water temperature of 55°C. He concluded that poor filterability came from the rind of the cane and hypothesised that it was extraction of waxes that caused the problem.

Garcia and Saska (1992) conducted a laboratory study on the effect of imbibition temperature on the extraction of polysaccharides and lignins. No results were presented.

Mill feeding

Khainovsky (1929) reported that, for a milling train set for cold maceration, mill capacity (feeding) initially drops when hot maceration is first used. When optimal mill settings for hot maceration are determined, capacity returns to the cold maceration level.

Sugar Research Institute (1955) found that increasing the imbibition temperature by about 30°C to 77°C resulted in an increase in mill speed.

Haines and Hughes (1962) found that mill feeding became noticeably more difficult at imbibition temperatures above 82°C.

Growth of micro-organisms

Moroz (1963), referencing the work of Hucker and Pederson (1930), reported on the presence of micro-organisms in juice, most notably *Leuconostoc mesenteroides*, that are known to cause dextran. He indicated that the temperatures for optimal growth of these micro-organisms was 21°C to 25°C but that the micro-organisms can grow within the wider temperature range from 5°C to 45°C. Moroz recommended temperatures over 65°C for good hygiene.

Factory experiments

Design

This section summarises the results of four factory experiments undertaken by the author into the effect of added water that have been conducted recently (Table 1).

Table 1—Summary of experiments to measure effect of added water temperature.

Factory	Year	Number of tests	Temperatures (°C)
Isis, Australia	2005	16	60, 98
Ledesma, Argentina	2006	4	57, 77
Plane Creek, Australia	2007	18	56, 75, 92
Macknade, Australia	2008	26	61, 92

At Isis and Ledesma, the cooler temperature was achieved through the use of a mixed juice heater, similar to those described by Leal *et al.* (1986), Castellat and Mendoza (1988), Bhojaraj (1990) and Nandagopal (1991).

At Plane Creek and Macknade, the cooler temperature was achieved by mixing the hot condensate with cool injection water, similar to the process described by Nigam *et al.* (1990).

Results

Expressed juice temperature

Figure 1 presents the average expressed juice temperatures for the three factories where measurements were made. Even though the added water temperature at each factory differed by over 30°C, the temperature of the mill 5 expressed juice differed by no more than 22°C, and the temperature of the mill 2 expressed juice differed by no more than 6°C.

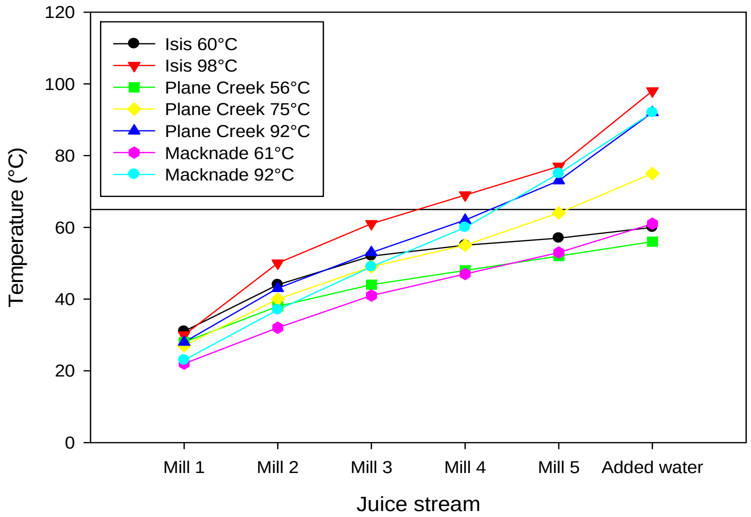

Fig. 1—Expressed juice temperatures.

A horizontal line has been drawn across the graph at 65°C, the temperature recommended by Moroz (1963) for good hygiene. The measurements show that, to achieve a juice temperature over 65°C on the final mill, the added water temperature needs to be above 75°C. A juice temperature over 65°C on the second last mill was only achieved with an added water temperature above 92°C. If a temperature above 65°C is to be achieved along the milling train, additional heating is required in the intermediate mills.

Delivery nip compaction

Figure 2 presents the average increase in delivery nip compaction from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance showed that the delivery nip compaction difference for mill 4 and mill 5 at Isis and all mills at Macknade was statistically significant.

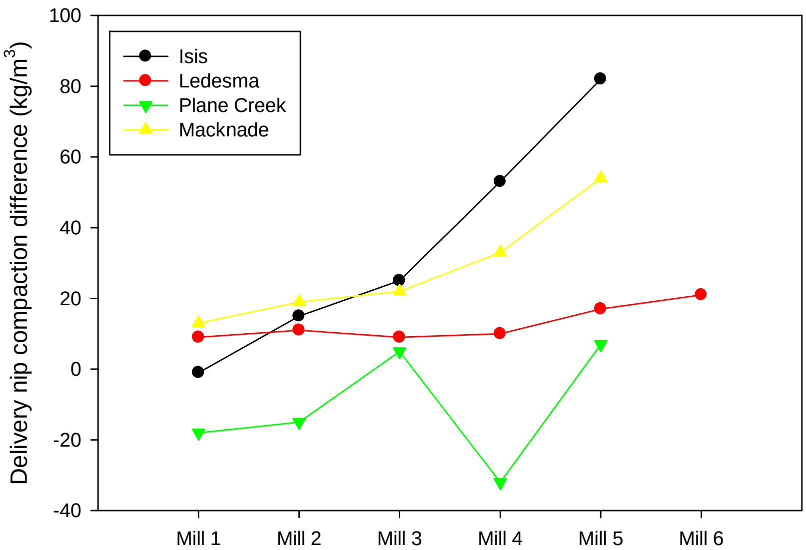

Fig. 2—Increase in delivery nip compaction from lowest to highest temperature added water.

The difference in delivery nip compaction has an increasing trend from mill 1 to the final mill in all cases, although the mill 4 result from Plane Creek is quite different. Figure 3 plots the increase in delivery nip compaction against the increase in juice temperature for the Macknade results and shows an almost linear trend. These results support the conclusion of Khainovsky (1929) that bagasse is more compressible at higher temperature.

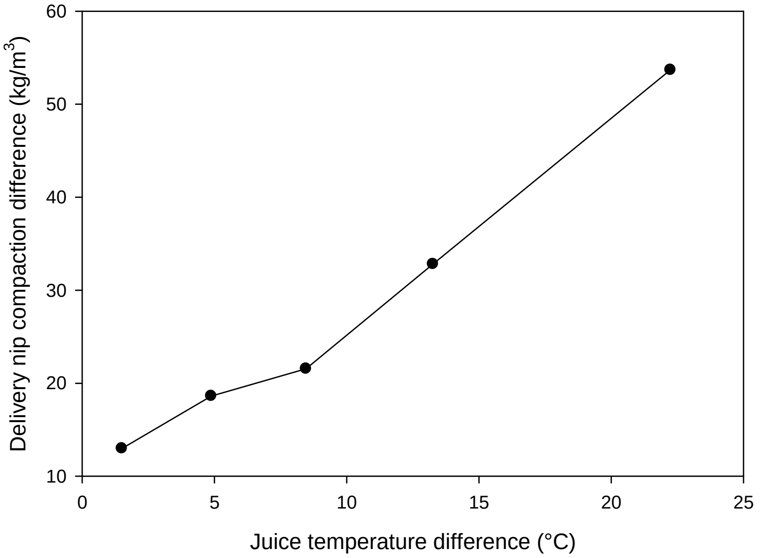

Fig. 3—Increase in delivery nip compaction as a function of the increase in juice temperature for the Macknade tests.

Total pol extraction and final bagasse moisture content

Table 2 presents the average increase in total pol extraction and average decrease in final bagasse moisture content from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance revealed that the extraction difference at Plane Creek and the moisture content differences at Isis and Macknade were statistically significant.

Table 2—Summary of average increase in total pol extraction and final bagasse moisture content from coldest to hottest added water.

Factory	Difference (%)	
	Extraction	Moisture content
Isis	0.0	–2.2
Ledesma	–0.2	1.3
Plane Creek	–0.8	1.1
Macknade	–0.1	–1.7

The Isis and Macknade bagasse moisture content results were both statistically significant and showed a reduction in bagasse moisture content with an increase in added water temperature, in line with the results of Khainovsky (1929). The Ledesma and Plane Creek results showed the opposite trend but were not statistically significant. Consequently, the Isis and Macknade results are considered a more reliable indicator of the true trend. These results support the delivery nip compaction results, since higher delivery nip compaction is expected to result in lower bagasse moisture content.

The delivery nip compaction and bagasse moisture content results support the argument that an increase in added water temperature will cause an increase in extraction. The Isis and Macknade results, where statistically significant bagasse moisture results were obtained, do not show this trend. The Plane Creek extraction results, which were statistically significant, show the opposite trend.

At Isis Mill, the cooler added water temperature caused a large increase in torque, beyond the ability of the control system to compensate. To limit the torque, the average added water rate was increased during the cool added water tests from 307 % fibre to 362 % fibre, a statistically significant difference. The increase in added water rate can be expected to increase extraction. Since no increase in extraction was observed during the cool added water tests, it can be concluded that the increase in extraction due to the higher added water rate was counteracted by a decrease in extraction due to the cooler added water temperature.

At Macknade Mill, although the order of tests was randomised, the ratio of pol to fibre in cane was higher during the cool added water tests (1.06 compared to 1.02), a statistically significant difference. Extraction can be expected to be higher when the pol to fibre ratio in cane is higher. Since no increase in extraction was observed during the cool added water tests, it can be concluded that the increase in extraction due to the higher pol to fibre ratio was counteracted by a decrease in extraction due to the cooler added water temperature.

While there is no direct evidence to show that an increase in added water temperature causes an increase in extraction, there is some indirect evidence that such a trend exists. These results support those of Khainovsky (1929), Sugar Research Institute (1955), Haines and Hughes (1962), Hugot (1986) and Ramasamy (1988). There is also, unfortunately, some contradictory evidence such as the Plane Creek Mill results. Weighing the evidence, the author believes that a small increase in extraction with an increase in added water temperature does occur but that it is difficult to measure. This increase is believed to be about 0.2 units of extraction, for an increase in added water temperature from 60°C to above 90°C. An analysis of the Macknade Mill results indicated a standard error in the extraction measurement of 0.6 units of extraction, at least partly explaining why an extraction difference is hard to detect.

Feed chute exit compaction

Figure 4 presents the average increase in feed chute exit compaction from the tests with the coldest added water temperature to the tests with the hottest added water temperature. Analyses of variance revealed that the feed chute exit compaction difference for mill 4 at Isis and mill 1, mill 3, mill 4 and mill 5 at Macknade were statistically significant.

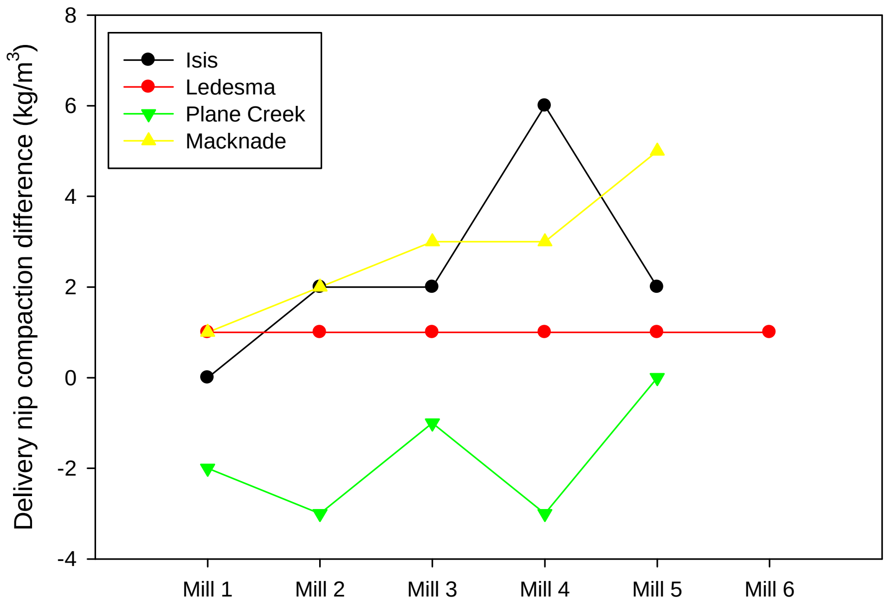

Fig. 4—Increase in feed chute exit compaction from lowest to highest temperature added water.

The Macknade results do show an increasing trend of feed chute exit compaction with added water temperature, like the delivery nip compaction trend. There is also some evidence of a trend in the Isis and Plane Creek results, although there is some contradictory data. Figure 5 plots the increase in feed chute exit compaction against the increase in juice temperature for the Macknade results and shows, as for the delivery nip compaction results, an almost linear trend. These results provide further evidence that bagasse is more compressible at higher added water temperature.

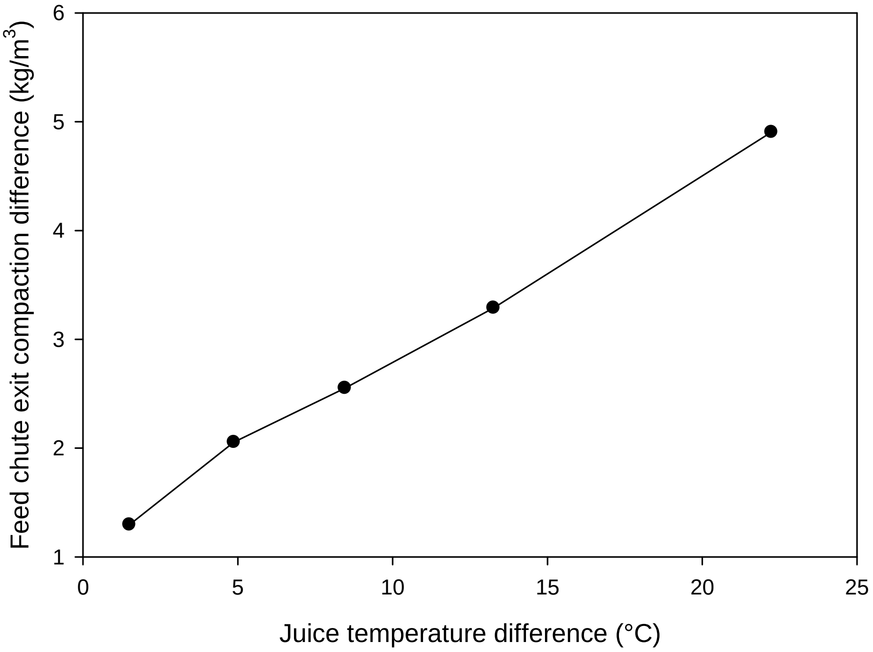

Fig. 5—Increase in feed chute exit compaction as a function of the increase in juice temperature for the Macknade tests.

The feed chute exit compaction is a strong indicator of mill feeding and mill capacity and, unlike mill speed, is independent of fibre rate and mill settings. Higher feed chute exit compaction indicates better mill feeding and correlates with lower mill speed. The feed chute exit compaction at the final mill at Macknade increased 7% by increasing the added water temperature from 61°C to 92°C.

Energy efficiency

As part of the experiment at Isis, where a mixed juice heater was used to cool the added water, the heating effect on mixed juice was also examined. By cooling the added water from 98°C to 60°C, the mixed juice temperature increased from 42°C to 54°C. As a result, the steam flow to the primary heaters reduced from 12.5 % cane to 10.8 % cane.

The fact that less steam was required for the cool added water case indicates that it is a more energy efficient option. In the cool added water case, some heat is transferred from the added water directly into mixed juice. In the hot added water case, heat is transferred from the added water to the bagasse and from the bagasse into mixed juice, with some heat lost either in vapour along the milling train and in bagasse. The hotter bagasse may also translate into an energy saving due to improved boiler efficiency, either by greater evaporation to reduce bagasse moisture content or by feeding hotter bagasse into the boiler. The size of this benefit has not been measured or estimated but may at least partly offset the higher juice heating requirement.

Conclusions

The effect of added water temperature on extraction has proven difficult to measure. There is little doubt that bagasse is more compressible at higher temperature. Two experiments have shown that bagasse moisture content is lower at higher temperature (1 to 2 units as added water temperature increased from 60°C to 90°C). These effects are most likely related. Two experiments produced indirect evidence of an increase in extraction with higher added water temperature (predicted to be about 0.2 units). One experiment provided direct evidence of a decrease in extraction with increasing added water temperature. This result is inconsistent with the remaining evidence but cannot be discounted. More research is required to better understand this extraction effect.

With bagasse being more compressible, mill capacity is increased at higher temperature (7% for the final mill at one factory, where bagasse temperature increased from 53°C to 75°C).

The use of a heat exchanger to cool added water with mixed juice reduces heat loss and consequently reduces steam usage for primary heating of juice.

Some of the lost heat may serve a useful purpose in increasing boiler efficiency resulting in more efficient use of bagasse, but this effect has not been measured.

Hotter added water does not appear to be a complete solution for mill hygiene. If bagasse needs to be heated above 65°C, even the hottest added water temperatures only provide sufficient benefit for the last one or two mills.

There remains considerably more work to identify the optimal added water temperature. The main outstanding issues are the effect of added water temperature on extraction, the effect of hotter bagasse on boiler efficiency through moisture content or temperature and the impact of bagasse temperature on hygiene.

Acknowledgements

The financial support of the Sugar Research and Development Corporation, Ledesma s.a.a.i. and CSR Ltd is acknowledged. Isis, Ledesma, Plane Creek and Macknade staff, in particular Mr David Pike, Mr Claudio Zapatero, Mr Paul Benecke and Mr Mick Conroy, provided considerable assistance in conducting the experiments. Mr Neil McKenzie and Dr Floren Plaza of QUT assisted in the conduct and analysis of experimental results.

REFERENCES

Bhojaraj, S.K. (1990). Development of imbibition water/mixed juice heat exchanger—an interesting auxiliary equipment. Technical Papers of the Annual Convention of the Deccan Sugar Technologists' Association (India), 40: E25–E29.

Castellat, I. and Mendoza, A. (1988). Heating of the mixed juice by using condensates. Proc. Asociacion de Technico Azucareros de Cuba, 45.

Chen, J.C.P. (1993). Outline of raw sugar process and extraction of juice. In: Chen, J.C.P. and Chou, C. (eds).Cane Sugar Handbook. 12th edition. John Wiley and Sons, New York, 48–102.

Clayton, J.L. (1971). System of Cane Sugar Factory Control. 3rd edition. QSSCT for the International Society of Sugar Cane Technologists, Brisbane, 87 p.

Doss, K.S.G. (1986). Improvements relating to extraction of sugar from sugarcane 'SAI (steam-aided-imbibition) process'. SISSTA Sugar Journal, Jul-Sep.

Garcia, T. and Saska, M. (1992). Effect of temperature of maceration water on mill extraction characteristics of polysaccharides and lignins. J. American Soc. Sugar Cane Technol., 12: 114.

Gonzalez, S. (1953). Effectos de la temperature del agua de maceracion sobre la filtrabilidad de los azucares. Proc. Asociacion de Technico Azucareros de Cuba, 27: 117–129.

Haines, W.S. and Hughes, R.H. (1962). Investigations on extraction in a commercial milling tandem. Proc. Int. Soc. Sugar Cane Technol., 11: 1013–1030.

Honig, P. (1953). The lipids in cane sugar manufacture. Proc. Int. Soc. Sugar Cane Technol., 8: 710–719.

Hucker and Pederson (1930). NY State Agr. Exptl. Sta. Tech. Bull. 167.

Hugot, E. (1986). Handbook of Cane Sugar Engineering. 3rd edition. Elsevier Science, Amsterdam, 1166 p.

Khainovsky, V. (1929). A study of milling and hot maceration of the bagasse. Proc. Int. Soc. Sugar Cane Technol., 3: 457–479.

Kumar, G.K. and Agrawal, K.N. (2000). Imbibition (a review and improvisation). Proc. Ann. Conv. Sugar Technologists' Association of India, 62: E72–E82.

Leal, D., Valdes, A. and Friedman, P. (1986). Decrease of the energy consumption at the sugar mills by an increase of the energy efficiency, Proceedings 2nd Energy Forum, Quivican.

Maxwell, F. (1932). Modern Milling of Sugar Cane. Norman Rodger, London, 423 p.

Moroz, R. (1963). Methods and procedures for the analysis of microorganisms in sugar. In: Honig, P. (ed.), Principles of Sugar Technology, 373–449.

Nandagopal, R. (1991). Heat recovery from imbibition hot water. SISSTA Sugar Journal, 17: 39–41.

Nigam, R.B., Banerjee, M.K. and Nath, A. (1990). Automatic control of imbibition water temperature. Proc. Ann. Conv. Sugar Technologists' Association of India, 52: E1–E7.

Ramaiah, N.A., Srivastava, S.K. and Tewari, L.P. (1979). A composition for reducing the pol and moisture in bagasse—'Sushira'. Proc. Ann. Conv. Sugar Technologists' Association of India, 43: E49–E75.

Ramasamy, P. (1988). Anomalies in hot water or steam aided imbibition super heated water aided imbibition, a new approach. Proc. Ann. Conv. Sugar Technologists' Association of India, 51: E15–E22.

Sugar Research Institute (1955). Maceration investigations. (I) Influence of quantity and temperature. Int. Sugar J., 57: 381.

Valdes, A., Leal, D. and Vasquez, C. (1994). Alternatives for a simultaneous heating of the mixed juice and cooling of the condensate for imbibition. Proc. West Indies Sugar Technol. Conf., 25: 309–317.

Von Czernicky, M. (1899). Archief, p. 147.

L'EFFET DE LA TEMPÉRATURE D'EAU AJOUTÉE SUR L'OPERATION ET LA PERFORMANCE DES MOULINS

Par

G.A. KENT

Queensland University of Technology, Brisbane, Australie

g.kent@qut.edu.au

MOTS-CLEFS: Ajoutés à l'Eau, Imbibition, Macération, Moulins, Extraction.

Résumé

QUATRE expériences récentes, faites en usines, ont été menées pour déterminer une température optimale de l'eau ajoutée. Les résultats n'ont pas été totalement concluantes mais ont fourni des détails supplémentaires sur l'effet de la température d'eau ajoutée. L'effet de la température d'eau ajoutée sur l'extraction s'est avéré particulièrement difficile à mesurer. Il y a peu de doute que la bagasse est plus compressible aux températures plus élevées. Deux expériences ont montré que l'humidité de la bagasse est inférieure à la température plus élevée. Ces effets sont probablement liées. Deux expériences montrent indirectement une augmentation de l'extraction par la température d'eau ajoutée plus élevée. La bagasse plus compressible augmente la capacité. L'utilisation d'un échangeur de chaleur pour refroidir l'eau ajoutée réduit les pertes de chaleur et par conséquent, réduit l'utilisation de la vapeur pour le chauffage principal du jus. Cela peut augmenter l'efficacité des chaudières, ce qui se traduit par une utilisation plus efficace de la bagasse. L'eau chaude ne semble pas être une solution complète pour l'hygiène du train de moulins étant donné que même l'eau la plus chaude a avantagée seulement le dernier ou les deux derniers moulins. Il faut beaucoup plus de travail pour identifier la température optimale d'eau ajoutée. Les principales questions restées sans réponses sont l'effet de la température d'eau ajoutée sur l'extraction, l'effet d'une bagasse plus chaude sur le rendement des chaudières à travers la teneur en humidité ou la température, et l'impact de la température de la bagasse sur l'hygiène.

EL EFECTO DE LA TEMPERATURA DEL AGUA ADICIONADA EN LA OPERACIÓN Y DESEMPEÑO DE UN TREN DE MOLIENDA

Por

G.A. KENT

Queensland University of Technology, Brisbane, Australia
g.kent@qut.edu.au

**PALABRAS CLAVE: Agua Adicionada,
Imbibición, Maceración, Molienda, Extracción.**

Resumen

SE EFECTUARON recientemente cuatro experimentos en fábrica para suministrar información en la búsqueda de la temperatura óptima del agua adicionada. Los resultados no fueron completamente concluyentes pero entregaron una visión adicional sobre el efecto de la temperatura del agua adicionada. Históricamente, este efecto ha sido particularmente difícil de medir. Hay pocas dudas en cuanto a que el bagazo sea más compresible a altas temperaturas. Dos experimentos mostraron que la humedad del bagazo es menor a temperaturas altas. Estos efectos están probablemente bien relacionados. Dos experimentos produjeron evidencia indirecta de un incremento en la extracción con la mayor temperatura del agua adicionada. Siendo el bagazo más compresible la capacidad de molienda se incrementa a altas temperaturas. El uso de un intercambiador de calor para enfriar el agua adicionada con jugo diluido reduce las perdidas de calor y consecuentemente reduce el consumo de vapor para el calentamiento primario del jugo. Algo del calor perdido puede ser útil para incrementar la eficiencia de calderas resultando en un uso más eficiente del bagazo. El agua adicionada mas caliente no parece ser una solución completa para la higiene del tándem dado que solo representa un beneficio, en el mejor de los casos, para el último o los dos últimos molinos. Todavía se requiere considerable trabajo para identificar la temperatura óptima para el agua adicionada. Los aspectos más sobresalientes son el efecto de la temperatura del agua en la extracción, el efecto de un bagazo mas caliente en la eficiencia de caldera, a través del contenido de humedad o la temperatura y el impacto de la temperatura del bagazo en la higiene del tándem.