DEVELOPMENT AND PROSPECTS FOR DRYING BAGASSE BY STEAM

By

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Abstract

DRYING of bagasse offers the advantage of an increase in calorific value and an improvement in boiler efficiency. Recovery of steam from the dryer for process heating increases the availability of bagasse as a fuel for cogeneration. A comparison of the impacts on the overall energy demand of a cane sugar plant employing flue gas drying and steam drying is given. The possibilities for integration of a bagasse steam dryer in the steam system of a cane factory are discussed. First test results and experiences gained with a steam drying pilot plant of 0.3 t/h water evaporation capacity are presented. Test conditions include drying of bagasse and fresh sugarcane to below 10% moisture. The plant has been operated for more than 1000 hours. In contrast to flue gas and low temperature drying, the steam dryer offers the advantage of a closed system. Air emissions can be reduced to a minimum by employing this technology. Steam drying of bagasse is also a measure to increase the electrical power production ( cogeneration). The gross calorific value of bagasse can be increased from 9000–10 000 kJ/kg (50% moisture) up to 18 000–19 600 kJ/kg. The boiler efficiency can be increased by up to 15% and the total electrical surplus power production by approx. 40–50 kWh/t cane. Impacts on the handling of dry bagasse, storage, boiler feeding and boiler design have to be considered and to be investigated further.

Introduction

The production of excess power has become of increasing interest as a valuable source of income for cane sugar factories. In order to maximise power production, the first aspect to be considered is the reduction of steam demand for the sugar process. Bagasse saved by applicable steam saving measures can be used in high pressure boilers and condensing turbines to increase the power production.

Concepts to reduce the steam demand to 20–25% on cane have been worked out by various authors (Avram-Waganoff and Stark, 2001; Broadfoot, 2002; Darcie, 2002; Morgenroth et al., 1995, Morgenroth, 2000; Wunsch and Avram-Waganoff, 1999). Some cane sugar mills, especially in Brazil, Mauritius and Reunion Island have moved forward and implemented many of these measures already.

Steam boilers with live steam pressures of up to 88 bar (a) have been applied in the cane sugar industry already and allow in combination with condensing turbines a further increase in power yield.

When these measures have been implemented, bagasse gasification and combined gas and steam processes can be applied. However, there is still a long way to go to be able to justify such processes from a technical and economical point of view. Bagasse needs to be dried (Turn, 1999) in order to be used in the most efficient way. Steam drying could provide the ‘missing link’ in the development of gasification.

Flue gas drying has been used for decades in the cane sugar industry (Gamgami, 1991). It is possible to increase the boiler efficiency by approx. 3–5% and to generate additional steam by this measure. Economically, it can be justified using the heat flow of the flue gas in the temperature range between ~ 180°C and ~ 80°C with flue gas drying. However, modern boiler waste heat recovery systems (Anon., 2001) can be applied as well in order to optimise the boiler efficiency to the same extent.

Flue gas drying does not solve the principal problem that all water in the wet bagasse has to be evaporated and the latent heat of the generated vapour is lost by sending it through the chimney.
Steam drying is a measure that allows recovery of the energy that is lost by evaporating water from bagasse because the vapour generated during the drying process is recovered in the sugar factory process.

Steam drying is not a brand new technology. It has been used in the beet sugar industry for beet cossette drying since 1982 in pilot plants (Pouillaude et al., 1988) and since 1990 on a technical scale (Jensen, 1995), and has also been applied to dry wood chips, coal, meat products and sewage sludge.

**Application of bagasse steam drying**

The following assumptions have been taken into consideration in order to elaborate the effect of steam drying (Table 1).

**Table 1—Base data for the calculations.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane crushing rate</td>
<td>20,000 t/day</td>
</tr>
<tr>
<td>Effective crop length</td>
<td>180 days</td>
</tr>
<tr>
<td>Fibre content in cane</td>
<td>14%</td>
</tr>
<tr>
<td>Bagasse flow rate</td>
<td>30% on cane</td>
</tr>
<tr>
<td>Bagasse moisture</td>
<td>50%</td>
</tr>
<tr>
<td>Gross calorific value of bagasse at 50% moisture</td>
<td>9583 kJ/kg</td>
</tr>
<tr>
<td>Steam demand of the sugar process</td>
<td>25% on cane</td>
</tr>
<tr>
<td>Backpressure</td>
<td>2.5 bar (a)</td>
</tr>
<tr>
<td>Boiler pressure</td>
<td>88 bar (a)</td>
</tr>
<tr>
<td>Superheated steam temperature</td>
<td>520°C</td>
</tr>
<tr>
<td>Boiler flue gas temperature</td>
<td>160°C</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>30°C</td>
</tr>
<tr>
<td>Ambient humidity</td>
<td>60%</td>
</tr>
<tr>
<td>Air ratio</td>
<td>1.3</td>
</tr>
<tr>
<td>Boiler house internal steam demand and losses</td>
<td>2%</td>
</tr>
<tr>
<td>Boiler feed water temperature</td>
<td>120°C</td>
</tr>
<tr>
<td>Isentropic efficiency of turbines</td>
<td>84%</td>
</tr>
<tr>
<td>Mechanical and electrical efficiencies of turbines</td>
<td>98%</td>
</tr>
<tr>
<td>Specific electrical power demand</td>
<td>28 kWh/t cane</td>
</tr>
</tbody>
</table>

Downing et al. (2002) investigated the potential of mechanical dewatering of bagasse and came to the conclusion that it is limited to approx. 40% moisture. Roll crushers rarely perform to the limit and an average of 43% moisture content would be considered excellent performance. A further moisture reduction of bagasse can be achieved by thermal drying methods.

Calculations for three scenarios were carried out:

- **Scenario 1**: Operation with a steam demand of 25% on cane for the sugar process using excess steam in a condensing turbine for power production.

- **Scenario 2**: Operation with a steam demand of 25% on cane for the sugar process using excess steam in a condensing turbine for power production and using flue gases at 160°C for bagasse drying.

- **Scenario 3**: Operation with a steam demand of 25% on cane for the sugar process using excess steam in a condensing turbine for power production and applying bagasse steam drying.

While scenario 1 is the base case, in scenario 2 it is assumed that the flue gases are used to dry bagasse to a moisture content of 42.5% which is the maximum value in this case. Flue gases of 160°C are cooled down to 80°C.

Table 2 gives an overview of the impacts of bagasse drying on the boiler performance. The heat losses caused by vapour from bagasse are reduced considerably by applying flue gas drying and further more with steam drying.

The boiler performance is increased by 12.3% when comparing the base case and scenario 3 with a bagasse moisture of 10%. With bone dry bagasse, the boiler efficiency can be raised up to 84%. In
combination with the increase of gross calorific value of the bagasse from 9583 kJ/kg to 17 295 kJ/kg, the steam production is increased by 96 t/h or 18.3% comparing scenarios 1 and 3. Combining flue gas drying or applicable boiler waste heat recovery systems can increase the boiler performance up to 87%.

Table 2—Boiler and bagasse data.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagasse moisture</td>
<td>%</td>
<td>50</td>
<td>42.5</td>
</tr>
<tr>
<td>Heat lost from water in flue gas</td>
<td>%</td>
<td>22.55</td>
<td>18.93 (boiler only)</td>
</tr>
<tr>
<td>Heat lost in dry flue gas</td>
<td>%</td>
<td>5.21</td>
<td>5.20</td>
</tr>
<tr>
<td>Unburned carbon losses</td>
<td>%</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Radiation losses</td>
<td>%</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Other losses</td>
<td>%</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Gross calorific value</td>
<td>kJ/kg</td>
<td>9583</td>
<td>11 029</td>
</tr>
<tr>
<td>Total steam generated</td>
<td>t/h</td>
<td>525</td>
<td>554</td>
</tr>
<tr>
<td>Boiler efficiency (GCV)</td>
<td>%</td>
<td>~69</td>
<td>~72.7</td>
</tr>
</tbody>
</table>

The integration of a steam dryer into the process is shown in Figure 1. Steam at 11 bar pressure is used for superheating vapour at 2.5 bar pressure. The superheated vapour will take up additional moisture from the bagasse.

The vapour generated by evaporation in the dryer is recovered by employing it in the first effect of the evaporation plant. This vapour is contaminated with volatile components and can not be sent back to the boiler or mixed with exhaust steam.
The hot condensate from the dryer is flashed to 2.5 bar and the flash vapour is recovered as well in the evaporation plant of the sugar factory. The live steam pressure applied is especially influenced by the surface of the superheater and consequently the investment costs. In scenario 3, high pressure steam at 11 bar is extracted from an extraction turbine and supplied to the steam dryer.

The effect of employing flue gas drying and steam drying on the production of surplus power is shown in Table 3. Flue gas drying allows an increase in the power output of about 9% compared to the base case. By steam drying of bagasse a power surplus of 17% can be achieved in the considered scenario. An additional power consumption of 1 kWh/t cane has been assumed for both drying technologies. Flue gas drying (or boiler waste heat recovery systems) could be combined with steam drying in order to increase power production further.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No drying</td>
<td>Flue gas drying</td>
<td>Steam drying</td>
</tr>
<tr>
<td>Assumed specific electrical power demand kWh/t cane</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td>Total power production MW</td>
<td>126.6</td>
<td>134.7</td>
</tr>
<tr>
<td>Excess power production MW</td>
<td>103.3</td>
<td>110.5</td>
</tr>
<tr>
<td>Specific power production kWh/t cane</td>
<td>152</td>
<td>162</td>
</tr>
<tr>
<td>Specific power export kWh/t cane</td>
<td>103</td>
<td>133</td>
</tr>
<tr>
<td>Total annual excess power production MWh</td>
<td>446200</td>
<td>477400</td>
</tr>
</tbody>
</table>

Exhaust steam and steam dryer vapour are supplied at the same pressure level to the first effect of the evaporation plant. Separate evaporators and condensate recovery systems need to be employed. In case falling film plate evaporators are operated in the first effect, the heating chamber can be divided into two chambers in the same evaporator. This has been done for a couple of installations in the beet sugar industry.

Environmental aspects of steam drying

Besides the fact that bagasse drying improves the production of ‘green’ electrical power, steam dryers operate as closed systems and produce no air emissions. The steam atmosphere prevents ignition, an ever-present danger with flue gas dryers. Dust problems are reduced also to a minimum.

Technical aspects

Steam dryer systems in other industries are usually operated by applying the fluidised bed technology. Bagasse is quite difficult to handle in this way as a homogenous fluidisation is almost impossible (Rasul et al., 1999). Fixed bed or rotary drum dryers are alternatives.

Another aspect is that handling of dried bagasse and feeding to the boiler might prove more difficult than with wet bagasse.

One of the most severe problems is the feeding–and discharge–of the dryer. Rotary valves and screw feeders supplying into and discharging from pressurised spaces are also exceedingly problematic with bagasse. The rotary feeders used for beet pulp have sophisticated systems to monitor rotor wear and to make adjustments during operation. Wear is likely to be higher with 50% moisture bagasse compared to 70% moisture beet pulp. Bagasse feeders would have to be significantly larger to accommodate the higher fibre rate, lower bulk density and choking propensity.

Boilers designed to operate on dried bagasse will be more compact. The saving in boiler cost compared to a conventional boiler designed to burn moist bagasse may be sufficient to offset a good part of the cost of bagasse drying, grinding equipment and ancillaries.

Experience with steam drying of bagasse and sugarcane

Prototype steam dryer for bagasse and sugarcane

In order to verify the feasibility of steam drying of bagasse, a prototype steam dryer with a nominal evaporation capacity of 0.3 t/h has been tested during the years 2003 and 2004 in two locations near Brisbane in Queensland, Australia.

Objectives of the test program have been:
- Determine drying rate parameters of bagasse in fixed beds using superheated steam.
- Test mechanical reliability and functionality of the feed, discharge and bed movement mechanisms.
- Evaluate potential fouling of heat transfer surfaces and screens.
- Confirm design parameters and validate design and performance data (bed area, depth, residence time, steam velocity, steam temperature) for commercial scale equipment.
- Measure physical and chemical changes during the drying process.

Fig. 2—Scheme of the bagasse prototype steam dryer.

Figures 2 to 4 display the set-up of the prototype dryer. Instead of high pressure steam, flue gases from a wood burner (heat rate 1 MW) have been applied to superheat the circulating steam. The lower pressure rating reduces equipment costs.

Fig. 3—Plan view on the 16 compartments and the bagasse ram feeder.
Flue gases of 500°C temperature are drawn by a fan through two tubular heat exchangers of 12 m² heating surface each. Circulating vapour passes down through the bed of bagasse, through the fan, twin tubular heat exchangers and back to the top of the vessel. The pilot plant is operated at atmospheric pressure. Steam exiting the heat exchangers may be heated to as high as 200°C. The maximum temperature is normally held to 180°C for drying bagasse and not greater than 160°C for drying shredded, whole sugarcane.

The problem of feeding and discharging bagasse from a sealed chamber has been tackled by the novel use of plug feeding and discharge. Hydraulic rams are used in the prototype to compress bagasse through a sealing chamber. Compaction of bagasse in a closed chamber feeding into the vessel and discharging from the vessel creates a sealing plug. Patent protection is pending on this and other novel features of steam dryers for highly fibrous materials.

![Fig. 4—Side view of the bagasse dryer pilot plant.](image)

Bagasse is transported from the feed sector to the discharge sector in sixteen strokes of the bed rotation actuator. Perforated screens are fixed over fifteen sectors leaving the final sector open. Screen area is 4 m². Dried bagasse falls through this opening to the chamber of the discharge ram. Residence time in the dryer may range from four minutes to several hours and is quite precisely controlled by sequence timing using a PLC.

**Results and prospects**

Reliable mechanical operation of the feed, bed movement and discharge mechanisms has been established. The prototype has been installed on a sugarcane farm on the Sunshine Coast to produce trial quantities of dried sugarcane. In this mode the plant has operated in excess of 1000 hours drying shredded, whole sugarcane from 70% moisture to less than 10% moisture.

Fouling of heat exchange surfaces and of screens after extended operation and with material containing high concentration of soluble carbohydrates is now well understood and managed by optimising perforated screen apertures and materials and maintaining the velocity of steam through tubes and bends.

Drying by downward flow of the drying medium (in this case superheated steam) through a fixed bed has the drawback of lower contact efficiency compared to fluidisation. Efficiency is further reduced if the resistance to flow is less in sections of the bed, due to uneven surfaces, holes or greater permeability as the material dries. Differential bed permeability has the largest impact on drying rates in the single stage prototype dryer. The resistance to flow is lower in the dryer part of the bed near the discharge sector.
compared to the wet material near the feed sector. Consequently, more drying steam passes through the dryer part of the bed. Differential flow is less pronounced when bagasse is dried from 50% moisture to 35% moisture compared to the single step drying of shredded, whole sugarcane from 70% moisture to 10% moisture. Consequently, drying rates in the prototype vary over a wide range for similar temperature and flow of superheated steam. Drying rates have ranged from 80 kg/h/m² for bagasse drying to 35% moisture and 185°C steam to a low of 15 kg/h/m² for drying from 75% moisture shredded whole cane to 8% moisture with steam at 155°C.

Downward flow through fixed beds has the distinct advantage of low headboard and fines filtering. The steam flow circuit is therefore less complex compared to fluidised bed dryers and pressure losses are lower. Beds may be stacked vertically to increase the screen area per unit volume of the dryer vessel to compensate for the lower drying rate per unit of screen area.

Lessons from prototype testing have been incorporated into a commercial-scale dryer that is to be installed in a new plant on the Sunshine Coast in Queensland to dry sugarcane for animal feed. The dryer will have a capacity of 15 t/h of evaporation and supply steam at atmospheric pressure to a triple effect evaporator. The material to be dried is a lightly pressed cane pulp. As in the pilot plant, circulating steam will be superheated by hot flue gas from solid fuel combustion.

Six stages are stacked vertically around the vertical shell and tube steam superheater. The total screen area will be 250 m². Each stage will have independent bed movement and fan systems to optimise the bed level and steam flow at each of the six stages. Remixed dried cane pulp and syrup produced from the pressed juice in the triple effect evaporator will be discharged at less than 12% moisture content. Each of the six centrifugal circulating fans will have a 100 kW motor.

Drying sugarcane has been a fortuitous but specialised application of steam drying technology at atmospheric pressure. The next step in the development of steam drying equipment for bagasse is to demonstrate sealing performance of the ram feed and discharge devices at an operating pressure of 2.5 bar. The development team intends to modify the vessel and relocate the prototype to an operating sugar mill for the final stages of testing.

Summary

Besides the conventional measures to reduce the steam demand of the sugar process, flue gas and steam drying of bagasse can contribute to increases in the electrical power yield. With steam drying of bagasse, power production is predicted to increase by about 17%. Boiler efficiency is predicted to increase to 81.3% if bagasse is dried to 10% moisture. Applying steam drying in combination with an energy optimised cane sugar factory, export of up to 145 kWh/t cane is possible.

Effective drying of bagasse and sugarcane to less than 10% moisture has been demonstrated in a 0.3 t/h prototype dryer operating at atmospheric pressure. A commercial-scale dryer for the production of animal feed from sugarcane is scheduled for operation by the end of 2004. The final stage of development of steam drying equipment for bagasse requires modification to the prototype vessel, relocation to a sugar mill and trial operation at 2.5 bar(a) pressure.

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The authors thank Professor Victor Rudolph of the Department of Chemical Engineering at the University of Queensland, Australia for advice, assistance and provision of laboratory facilities. Testing of the prototype steam dryer was supported by a QSEIF grant from the Queensland Government.

REFERENCES


**LE SÉCHAGE DE LA BAGASSE À LA VAPEUR : DÉVELOPPEMENTS ET PERSPECTIVES**

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**MOTS CLEFS:** Séchage Bagasse, Vapeur, Cogeneration.

**Résumé**

LE SÉCHAGE de la bagasse est avantageux en termes de la valeur calorifique et de l’efficience des chaudières. On peut aussi se servir de la vapeur de sortie du sécheur comme source d’énergie pour la fabrication ; cela donne permé l’utilisation de la bagasse pour la cogénération. On a compare l’utilisation des gaz de cheminée a celle de la vapeur pour le séchage, et on étudie les effets de ces deux sources sur la demande d’énergie dans une sucrerie de cannes. La possibilité d’intégrer un sécheur de bagasse à vapeur dans une sucrerie est discutée. On présente des résultats obtenus avec un sécheur a vapeur, a l’échelle pilote, avec une capacité d’évaporation d’eau de 0.3t/h. On a teste le séchage de la bagasse et de la canne jusqu’à moins de 10% d’humidité et on a fait travailler le sécheur pour plus de 1000 heures. Le sécheur a vapeur offre l’avantage d’un système fermé, contrairement aux gaz de cheminée et du séchage a température basse. Cette technologie permet une grande réduction des émissions aux gaz de cheminée. Le séchage a la vapeur permet aussi la cogénération. On peut augmenter la valeur calorifique de la bagasse de 9000–10000 kJ/kg (humidité 50%) jusqu’à 18000–19600 kJ/kg. L’efficience de la chaudière augmente de 15% et la production d’énergie augmente par 40–50 kWh/t cannes. La manutention de la bagasse séchée, son entreposage et son alimentation dans les chaudières demandent des investigations.
DESARROLLO Y PERSPECTIVAS DEL SECADO DEL BAGAZO MEDIANTE VAPOR
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PALABRAS CLAVE: Secado del Bagazo, Secado por Vapor, Cogeneración.

Resumen

EL SECADO del bagazo ofrece la ventaja de incrementar su valor calorífico, así como de mejorar la eficiencia de la caldera. La recuperación de vapor de la secadora para el calentamiento del proceso aumentará la disponibilidad del bagazo como combustible de cogeneración. Se proporciona aquí una comparación entre impacto en la demanda general de energía de una planta azucarera que emplee secado con gas líquido y secado con vapor. Se discute la posibilidad de integrar una secadora de vapor para el bagazo al sistema de vapor del ingenio. Se presentan los primeros resultados de las pruebas y experiencias conseguidas con el uso de una planta piloto secadora de vapor, con capacidad de evaporación de agua de 0.3 t/h. Las condiciones de las pruebas incluyen el secado del bagazo de la caña de azúcar fresca a menos de 10% de humedad. La planta se ha operado por más de 1000 horas. Al contrastarse el secado con gas líquido y el secado a baja temperatura, la secadora de vapor ofrece la ventaja de ser un sistema cerrado. Las emisiones de aire pueden reducirse a un mínimo mediante el empleo de esta tecnología. El secado del bagazo por medio de vapor es también una medida que incrementa la producción de energía eléctrica (cogeneración). El valor calórico bruto del bagazo puede incrementarse de 9000–10 000 kJ/kg (50% humedad) hasta 18 000–19 600 kJ/kg. La eficiencia de la caldera puede incrementarse hasta en un 15% y la producción total de energía eléctrica excedente hasta, aproximadamente, 40 a 50 kWh/t caña. Habrá que considerar e investigar más el impacto en el manejo del bagazo seco, su almacenamiento, alimentación de las calderas y el diseño de las mismas.