REFEREEED PAPER

THE DEVELOPMENT OF A DOUBLE HEADSHAFT, MOVING CHAIN DIFFUSER: DESIGN, INSTALLATION AND PERFORMANCE

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Abstract

The trend towards larger extraction lines requires the use of wider diffusers. The widest diffusers installed in the southern African industry are the 12 m wide Tongaat Hulett (TH) diffusers at Felixton factory. A moving chain diffuser is essentially a large slat conveyer which drags cane fibre slowly across a perforated screen, allowing sucrose to be separated from the fibre through counter current washing. The torque and bending moment on the headshaft increases non-linearly with the width of the diffuser, making it both impractical and expensive to substantially increase the size of current chain diffusers. For this reason TH has developed a new chain diffuser design, replacing the single headshaft with two separately driven headshafts. The double headshaft design will permit cost-effective chain diffusers up to a width of 22 m to be constructed. This paper discusses the design, installation and performance of the latest TH double headshaft 14 m wide diffuser which was installed in 2018 at Korach Industries factory in Phimai, Thailand.

Keywords: diffusion, bagasse diffuser, headshaft, extraction, crushing capacity

Diffuser development in South Africa

Voigt (2009) provided a comprehensive summary of the history of cane diffusion and in particular its development in South Africa. While milling is still most common elsewhere in the world, the progress in diffuser understanding, design and performance which has been a collective effort of a number of South African sugar technologists, has encouraged its uptake in other countries. These technologists include: Renton and van der Riet (1971), who overcame the initial problems of poor percolation with the invention of lifting screws, a feature of all modern diffusers; Rein (1974, 1980) and Love and Rein (1980), who contributed substantially to the theoretical understanding of diffusion; Rein and Ingham (1992), who reported on the design and benefits of the adjustable sprays installed at Felixton which are now widely used, and Meadows et al. (1998), who showed that the mud filters are not required in diffusion factories. Rein (1995) showed that diffusion incurs less capital and maintenance costs and higher extractions than milling.

One limitation to the competitiveness of diffusion versus milling was the ability of milling tandems to process more cane. This changed when the Bosch chainless diffuser (Voigt, 2009) allowed for the construction of wide diffusers, capable of matching the capacity of large milling tandems. The Bosch diffuser eliminated the heavy headshaft associated with wide chain diffusers, and capitalised on the structural advantage of supporting the diffuser deck with rows of columns underneath. The new TH double headshaft diffuser continues the trend of diffuser innovation by South African technologists.

Korach diffuser description

Korach Industry’s factory in Phimai, Thailand processes approximately 30 000 tons cane per day (tcd) in a single milling line. In 2018, a second line was installed to add an additional
capacity of 19 600 tcd using a bagasse diffuser. The targeted extraction from the bagasse diffusion line is between 97.6% and 98%, depending on the cane quality. Other features of the diffuser are described in Table 1, with a photograph of the diffuser in Figure 1.

Table 1. Features of the 14 m wide bagasse diffuser installed at Korach Industries.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (tch)</td>
<td>820</td>
</tr>
<tr>
<td>Extraction length (m)*</td>
<td>57.5</td>
</tr>
<tr>
<td>Diffuser internal width (m)</td>
<td>14</td>
</tr>
<tr>
<td>Design bed height (m)</td>
<td>1.8</td>
</tr>
<tr>
<td>Stage length (m)</td>
<td>5</td>
</tr>
<tr>
<td>Press water heating</td>
<td>Direct contact</td>
</tr>
<tr>
<td>Diffuser heating</td>
<td>Direct steam injection into 6 trays</td>
</tr>
<tr>
<td>Scalding juice heating</td>
<td>2 shell and tube heaters</td>
</tr>
<tr>
<td>Infeed carrier</td>
<td>Angled carrier, 3m wide</td>
</tr>
<tr>
<td>Lifting Screws</td>
<td>3 sets of 14 screws</td>
</tr>
<tr>
<td>Clarifier mud recycle</td>
<td>yes</td>
</tr>
<tr>
<td>Plate material</td>
<td>3CR12 stainless steel</td>
</tr>
<tr>
<td>Juice application</td>
<td>Spray pipes with adjustable deflectors</td>
</tr>
</tbody>
</table>

*Measured from the infeed wall to the middle of the press water drum

Figure 1. The 14 m Tongaat Hulett diffuser installed in Phimai, Thailand.

Cane fibre transportation, and headshaft design

The TH diffuser transports the shredded cane fibre by dragging it across a perforated plate using ‘ladders’ made up of slats and chains (Figure 2).

Figure 2. Chain and slat ladders in the Tongaat Hulett 14 m wide diffuser.
This method of transporting the cane allows:

- Fixing the perforated plates securely in position which prevents fibre from bypassing the screens and potentially blocking interstage pipes, or spray nozzles.
- Continuous ‘cleaning’ of the screen with the action of the cane bed being dragged across the perforated plate. This prevents bagasse becoming lodged in the 10 mm perforations where it would reduce the flowrate of juice through the bed.
- A heavy press water drum. The strong pulling action of the chain and slats on the cane allows it to be squeezed under the heavy drum to reduce the moisture of bagasse leaving the diffuser (commonly termed megasse).
- High bed heights (up to 1.8 m) which allows the residence time of cane in the diffuser to be maximised, leading to high sucrose extraction.

While the chain pull to overcome the friction between the cane and the diffuser is substantial, the power requirement is low as a result of the low speed of the cane bed (approximately the same power as an interstage pump motor on each drive).

The chains are pulled by sprockets mounted on a headshaft. For the 14 m wide diffuser, seven ‘ladders’ are used, which requires 14 chains and therefore 14 sprockets on the headshaft. The headshaft is designed to overcome both bending moment (BM) and torsion (resulting from the twisting of the sprocket on the shaft). With wide diffusers, the torsion can be halved by driving the shaft from both ends. The bending moment is, however, the largest of the two forces and can only be reduced by shortening the shaft. It was for this reason that TH Technology Group (TG) designed the diffuser with two independent headshafts. Figure 3 compares the torsion and bending moment between a single and double headshaft for a 14 m wide diffuser with a 1.8 m bed height. The bending moment for the double headshaft is about 4.5 times lower than for a single headshaft.

![Figure 3. Comparison of bending moment and torsion between a double headshaft and a single headshaft driven from both ends.](image)

If a single headshaft was used for a 14 m diffuser, an appropriate Pitch Circle Diameter (PCD) of the sprocket would be 2 247 mm (seven teeth, 500 mm chain pitch) to allow the diameter to be large enough to withstand the bending stresses. The shaft would weigh in the order of 130 tons and require specialised (and costly) casting, welding, transportation and lifting on site. The large diameter shaft requires two drives, one either end, with about 40% higher torque and gear ratios than for the split shafts. Table 2 compares the shafts and gearbox requirements for a double and single headshaft.
Table 2. Comparison of shafts and gearboxes for single and double headshaft.

<table>
<thead>
<tr>
<th></th>
<th>Single shaft</th>
<th>Double shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft Mass (t)</td>
<td>130</td>
<td>33 (x2)</td>
</tr>
<tr>
<td>Sprocket PCD (mm)</td>
<td>2247</td>
<td>1618</td>
</tr>
<tr>
<td>Shaft Speed (rpm)</td>
<td>0.12</td>
<td>0.17</td>
</tr>
<tr>
<td>Gearbox Ratio</td>
<td>7436</td>
<td>5407</td>
</tr>
<tr>
<td>Gearbox Torque</td>
<td>3630</td>
<td>2614</td>
</tr>
</tbody>
</table>

Figure 4 shows the two headshafts after installation. A removable nose plate (not shown) is located above the centre bearings to keep the megasse away from the bearings, and to enable the bearings to be easily and safely inspected when required. The sealed bearing housings are continuously pressurised with grease to prevent the ingress of dust and moisture into the bearing (Figure 5).

**Figure 4. Double headshaft during installation.**

**Figure 5. Inner bearing housings showing chains and slats of the centre ladder as well as grease lines to the bearing housings.**

*Shaft synchronisation*

With the double headshaft diffuser, the centre two chain strands are located on different shafts. Given that these two strands are connected with slats, it is imperative that the two shafts turn at the same speed. If the shafts are out of position by more than 3 degrees, the slats in the centre ladder would become damaged, and could damage the chains in which they are mounted. The first step to keeping the shafts in sync is being able to accurately measure their position. This is achieved with absolute, multiturn encoders mounted on the motor shafts of each drive. Once the shafts are aligned, the encoder positions are set, and the two shafts then behave as a single electronically linked shaft. For a headshaft misalignment of 1 degree, the
corresponding encoder misalignment is 5 407 degrees (gearbox ratio) or 15 motor rotations. While 3 degrees is the maximum allowable misalignment, the drives are programmed to stop if the misalignment reaches 1 degree.

While numerous acceptable control philosophies exist for maintaining the shafts in sync with each other, the standard pre-programmed drive feature was used with good results. The basic philosophy is:

- The motor speed (rpm) is selected by the operator to achieve the targeted bed height.
- A speed setpoint is generated and sent to each of the headshaft drives, where their speeds are controlled using a PID controller.
- The angular position of each of the headshafts is monitored (by multiplying the multiturn encoder position by the gearbox ratio) and displayed (Figure 6).
- The difference between the two positions is displayed. If the positions are more than 1° apart, then the drives will stop.

![Figure 6. Parameters for the two headshaft drives which are displayed in the control room.](image)

The speeds of the two headshafts are maintained by adjusting the speeds of their motors. The variation in motor current, and headshaft speeds (for a speed setpoint of 1 000 rpm) is shown in Figure 7. During normal operation the variation in headshaft position was undetectable at 2 decimal places. When the diffuser stopped, the shafts could go out of position by up to 0.6°. Upon restarting the diffuser, the shafts are first realigned to zero offset before they start running. There have been no cases of the diffuser stopping due to the shafts being more than 1° out of alignment.

![Figure 7. Speed and current readings for both headshaft motors over 40 s of operation.](image)
Cane Distribution

A diffuser functions best with a flat cane bed. If the bed is not flat, liquid applied to its surface will preferentially flow to the low points which could lead to reduced extraction from the cane under the high points. A sloping bed of more than 1 m can cause the press water drum to contact the side edge of the diffuser, and if the bed is higher than 2.5 m anywhere, it can damage the juice spray deflectors. A reasonably flat bed is also required to provide a seal in the feed and discharge end of the diffuser; deep ruts in the bed can allow channelling of juice under the infeed wall or the press water drum.

The wider the diffuser, the greater the challenge of maintaining a level bed. For this reason, the infeed carrier was increased from 2.1 m for the Tongaat Hulett 9 m diffuser, to 3 m for this 14 m diffuser. A photograph and drawing of the carrier is shown in Figure 8. The carrier is aligned at an angle to the diffuser so that the bagasse falls parallel to the diffuser feed wall. To achieve a flat bed, the cane must be distributed across the full width of the infeed carrier. This is achieved using adjustable fingers to deflect the cane as it falls onto the infeed carrier.

Figure 8. Photograph and diagram of the infeed carrier for the Korach diffuser.

During commissioning, the interstage pumps remained off while the adjustments were being made to set the bed level to improve the sight into the diffuser. Figure 9 shows the flat bed that was achieved during commissioning.

Figure 9. Flat bagasse bed achieved during commissioning of the Korach diffuser.
One advantage with a double headshaft diffuser is the ability to track and compare the loads on each headshaft drive. A consistent difference in load (drive Amps or Torque) is an indication that the diffuser is being preferentially loaded (either with bagasse or juice) on one side. Figure 10 shows two half-hour periods, one where the master shaft was carrying slightly more load, and the other when the slave shaft was carrying more load. A prolonged and substantial difference is a signal to the operator to check the bed level and juice spray distributions.

Figure 10. Graphs showing the difference in load on the two headshaft drives over two different half hour periods.

Washout protection

Under normal circumstances, the cane falls from the infeed carrier onto the diffuser screen, and forms a seal between the screen and the vertical infeed wall. This seal prevents juice from escaping from the diffuser under this wall. The movement of cane fibre towards the headshaft also transports juice away from the infeed wall. Under certain circumstances, the seal can be lost which can result in bagasse and fibre spilling onto the floor beneath the diffuser. Factors which cause this feed wall washout are:

- Stopping the diffuser for a prolonged period but keeping the interstage and scalding juice pumps on. With the bed stationary, more juice than normal is transported to the feed end. In particular, if the draft juice is not being pumped from the diffuser due to a downstream constraint (which is usually the reason for stopping the diffuser) then a large amount of juice can end up forming a ‘dam’ on the fibre bed. If a gap in the fibre seal presents itself, this ‘dam’ is likely to flow out of the diffuser and onto the floor.
- Poor cane distribution across the width of the diffuser can lead to a break in the fibre seal at the feed wall
- Re-starting a stopped diffuser before cane is added will lead to the seal being broken
- Poor throughput control can also lead to gaps in the seal.

While all of these factors are avoidable through good diffuser operation, the TH diffuser has incorporated a raised section between the feed wall and the tail drum (Figure 11) so that in the event of washout, juice and fibre are contained. The juice can flow back into the draft juice tray through perforations in the raised screen, and the fibre is returned into the diffuser by scrapers on alternate slats.
Figure 11. Raised section between the infeed wall and the tail drum.

**Deck support**

The deck of a single headshaft diffuser is normally unsupported. With wide diffusers, this requires heavy transverse beams to resist the bending moment. Supporting the deck with columns between the chains is a better solution, but the small gap between the chains in diffusers does not normally allow this. The concept of the chainless diffuser (Voigt, 2009) showed that substantial ‘bridging’ occurs between cane fibres, and that the chain spacing need not be so close. The new TH design has widened the space between the ladders thereby allowing the deck to be supported by standard pinned columns as shown in Figure 12. Deflectors were attached to the columns to minimise the risk of the chain snagging. Trip wires were also added above and below the chain so that any change in chain tension (which would be caused by snagging a column) would stop the diffuser before damaging the structure.

Figure 12. Pinned columns between the chain ladders and trip wires to detect changes in chain tension.

**Chain wash return**

One of the negatives of a chain diffuser is the small amount of bagasse which remains on the chain after it rounds the headshaft. To prevent excessive droppings, especially at the tail shaft end where the chain turns upside down, the bagasse should be washed from the chain as it leaves the diffuser. This washing also helps to remove sand from between the links thus prolonging the life of the chain. Imbibition water is used to wash the chain. The water (along with bagasse fibres) is then pumped to the diffuser where it should be distributed across the
full width of the diffuser. Sprays are not suitable for this application as they would block with fibre. An overflow weir is normally used, but this also has a tendency to fill with fibre and compromise the chain wash distribution, which is approximately 1/3 of the total imbibition.

The Korach diffuser returns the chain wash water to a tray, but uses clean imbibition through sprays to continuously flush the fibre from the tray (Figure 13). This proved to be an effective solution to ensure that all imbibition was evenly distributed across the width of the diffuser.

![Figure 13. Chain wash return and imbibition without and with flow.](image)

**Diffuser performance**

The diffuser was commissioned in March 2018 along with the rest of the new KI factory. While the design capacity of the extraction line is 820 tch, its throughput was limited to 500 tch as a result of limited boiler capacity. The effect of this was the sub-optimal position of the juice sprays, and difficulty in maintaining a well wetted bed. A number of stoppages due to the commissioning of other parts of the factory also resulted in intermittent diffuser operation. Nevertheless, some data was obtained, and extraction averaged about 97% (Figure 14), and it is expected that when the factory settles into stable production, 98% will be achievable.

![Figure 14. KI diffuser extraction performance in first week of operation](image)
Conclusions

Since the 1960s, South Africa has been at the forefront of diffusion technology in the sugarcane industry. The advantages of diffusion over milling are reduced capital and operation costs, improved extraction, and the ability to process clarifier mud without a mud filtration station. Until recently, the main disadvantage with diffusion was the ability of milling tandems to process more cane. The first double headshaft diffuser was installed at Korach Industries’ Thailand factory in 2018. This 14 m wide bagasse diffuser has a design throughput of 820 tch. The double headshaft avoided the costly fabrication, transportation, installation and drives which would have been required for a 14m single headshaft. The combined weight of the two shafts is about half the weight of a single shaft as a result of the large reduction in bending moment. The diffuser deck is supported by pinned columns located between the return strands of the chain. The success of this design allows for wider diffusers to be constructed from standard structural steel profiles. Other features which have resulted in the good performance of the old TH diffusers were included in the new design namely: adjustable sprays, effective cane feeding to maintain a flat 1.8m bed, and a heavy press water drum which reduces the load on the de-watering mills. The new double headshaft diffuser allows diffusers up to 22 m wide, capable of processing 1 000 tch cane, or 1 500 tch bagasse to be built cost effectively.

REFERENCES