M7 - PERFORMANCE OF AN IMPROVED PAN STIRRER AT ISIS SUGAR MILL

By

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Abstract

A set of impeller blades of new design was retrofitted to the stirrer in the Isis No. 4 pan for the 2004 season. The design of the new impeller blade was based on the results obtained from experimental trials and from computational fluid dynamics (CFD) modelling undertaken by SRI over the past few years.

During the 2004 season the performance of the new impeller blades was evaluated for different grades of massecuite in terms of:

- Heat transfer coefficients for the pan;
- Circulation measurements at various locations within the pan; and
- Power consumption of the stirrer at various speeds.

The evaluation data collected during the 2004 season are compared with data obtained during the 2001 and 2002 seasons on the same pan when fitted with the original stirrer design. Comparisons of performance for both types of stirrer designs are detailed.

CFD studies were also conducted to assess the performance of the new impeller blades under various operating conditions. These results are also discussed.
Introduction

The retrofit or installation of stirrers into batch vacuum pans can be very beneficial to their performance; however, the results do not always match the expectations. Benefits that have been attributed to the increased circulation provided by stirrers include:

- Reduced strike times for boiling cycles in pans. According to Webre (1962) this could be as much as 20-30% for high-grade strikes and up to 50% for low-grade strikes;
- Improved heat transfer coefficients (HTC), especially towards the end of the strike. This may increase the rate of evaporation by up to four times (Webre, 1962);
- Increased uniformity of massecuite conditions within vacuum pans, thus reducing the risk of producing fine grain. This allows the pan to be boiled at a higher level of supersaturation and hence with increased crystallisation rates (Tait *et al*., 1995);
- Less scaling on the heating surface due to reduced overheating of the massecuite near the heating surface (Webre, 1962);
- Reduced usage of movement water and steam to give the desired amount of circulation (Jenkins, 1941; Tait *et al*., 1995);
- Increased ability to use low-pressure vapour (Jenkins, 1941), e.g. vapour bleed from the evaporator set, leading to increased steam efficiency for the factory;
- Increased operating capacity of the pan by raising the maximum boiling level by as much as 300 mm (Webre, 1962); and
- Improved quality of sugar and purity drop for the product massecuite (Jenkins, 1941).

Retrofitting a stirrer into a key batch pan can be a very cost effective way to increase the pan stage productivity.

The primary disadvantage of retrofitting a stirrer into a vacuum pan is the financial cost which includes the initial cost of installation and the on-going costs of maintenance and power consumption. Often the top cone of the pan has to be strengthened to support the motor and gearbox.

Apart from recent work at SRI, very little published research has been undertaken in the Australian sugar industry to develop a stirrer design for Australian processing conditions. Traditionally, the design of stirrers has largely been left to the heavy engineering equipment manufacturers. Stirrer designs for centre well pans are generally four or six bladed pitch blade turbines of mixed flow characteristics.

This paper shows that CFD modelling techniques have been used successfully to improve stirrer designs in batch vacuum pans. The work undertaken in this study is for centre well pans which are the most common design in the Australian sugar industry.
Criteria for determining the optimum stirrer design

There are a number of factors that influence the performance of stirrers. These include the positioning of the impeller within the pan, the diameter of the impeller with respect to the downtake diameter, the angle of attack of the blades (variable or constant) and the solidity of the blades (cross-sectional area of the blades in plan view relative to the downtake cross-sectional area). These factors affect the circulation velocity of the massecuite and consequently the heat transfer performance.

The objective of this study was to design a stirrer that circulates a large volume of massecuite for a fixed amount of power. In other words, a stirrer design of low power input/pumping volume was sought. However there are other criteria which should be satisfied. Increasing the circulation rate of the massecuite through the pan has a strongly positive effect on the heat transfer. Of particular importance is the necessity to have a relatively high velocity of massecuite to the tubes in the outer region of the pan, as this region contains a large proportion of the heat transfer area.

Two dimensionless parameters are used to quantify the efficiency of the stirrer. The Power number, \( N_p \), defines the amount of power required to circulate the massecuite. The Pumping Capacity number, \( N_Q \), defines the volume of massecuite transferred by the impeller. The ratio \( N_p/N_Q \) defines the power efficiency of a stirrer, with low values indicating increased power efficiency. In this study, this ratio is used as the primary method of determining the efficiency of the stirrer.

The Power number is expressed by,

\[
N_p = \frac{P}{N^3 D^5 \rho} \quad (1)
\]

where \( P \) is the consumed stirrer power (W), \( N \) is the stirrer rotational speed (r/s), \( D \) is the diameter of the stirrer (m), and \( \rho \) is the density of the fluid (kg/m\(^3\)).

The Pumping Capacity number is expressed by,

\[
N_Q = \frac{Q}{N D^3} \quad (2)
\]

where \( Q \) is the volumetric flow rate, m\(^3\)/s.

The values of \( N_p \) and \( N_Q \) depend on the geometric parameters for the system such as clearance between the impeller and the bottom of the vessel, the shape of the bottom of the vessel (flat, conical, profiled, and so on) and parameters which define the impeller (blade angle, solidity).

When flow through the impeller is laminar (e.g. in agitating liquids of high viscosity), the Power number \( N_p \) is approximately inversely proportional to the Stirrer Reynolds number \( (Re_{stirrer}) \), which is defined as,

\[
Re_{stirrer} = \frac{N D^2 \rho}{\mu} \quad (3)
\]
where $\mu$ is the dynamic viscosity of the fluid (Pa.s). For flow within the impeller region laminar flow exists for $Re_{stirrer}$ values less than ~10. Transitional flow occurs for $Re_{stirrer}$ values between 10 and 10 000 and turbulent flow for $Re_{stirrer}$ values greater than 10 000. Laminar flow conditions at the impeller only exist when processing low grade massecuites during heavy up. This is the condition of the highest load on the stirrer motor. Note: According to convention, $Re_{stirrer}$ is calculated for stirrer speed as r/s and not radians/s.

For laminar flow, the power expression simplifies to,

$$ P = K \mu N^2 D^3 $$

where $K$ is the proportionality constant for the system.

Several rules of thumb are commonly used in the design of stirrers. These rules assume that the flow through the impeller region is laminar and that Equation 4 adequately describes the system. The rules of thumb are:

1. Maximum blade tip speed should be less than 5 m/s.
2. Installed power of stirrer should be 1.5 to 1.6 kW/m$^3$ for C massecuite.
3. Installed power of stirrer should be 1.0 to 1.2 kW/m$^3$ for A and B massecuite.
4. Power law proportionality constant ($K$) in Equation 4 is $5.76 \times 10^{-2}$ for the impeller design (pitched blade turbine) evaluated by Bentley et al. (1988). This constant has been used as a rule of thumb for determining power consumption in stirred pans even though it is specific to that single stirrer configuration.

Development of the improved stirrer design

SRI undertook a major study to develop an improved design of stirrer for sugar vacuum pans of the centre well design (Rackemann et al., 2004). This study involved the following steps:-

1. Develop a CFD model of stirred batch vacuum pans of the centre well design.
2. Undertake velocity and torque measurements in a 1/20$^{th}$ scale pilot pan at CSIRO to provide validation data for the CFD models. These studies were undertaken for different impeller designs, stirrer speeds, and viscosities of the fluid.
3. Obtain circulation velocity data on the No. 4 pan at Isis Mill to provide validation data for the CFD model. These experiments are described in the section to follow.
4. Validate the CFD models using the CSIRO and Isis pan data.
5. Apply the validated CFD models to determine the improved design of impeller to suit A, B and C massecuites.

The impeller blades of the improved design were installed in the No. 4 stirred pan at Isis Mill for the 2004 season.

Factory trials conducted on No. 4 batch stirred pan at Isis Sugar Mill

The Isis No. 4 pan was selected to obtain circulation and heat transfer data because it produces A, B and C massecuites, has sufficient access underneath the pan to insert circulation measurement probes, has a large amount of excess capacity for its stirrer motor, and is a modern design of batch pan.
SRI staff visited Isis Sugar Mill in 2001 and 2002 and obtained circulation and heat transfer data for the pan (on 20 pan cycles) with the originally supplied stirrer. This stirrer is a four bladed pitched blade turbine with relatively narrow blades of variable pitch from the hub to the tip. The centreline of the impeller blade was positioned in line with the bottom tube plate for both the original arrangement and, in the 2004 season, when new blades were fitted.

During the testing in 2001 and 2002, hot wire anemometer probes were inserted into the bottom of the pan in order to obtain velocity data for the A, B and C massecuites. The locations of the anemometer probes are shown in Figure 1 and are defined as location X, location Y and location Z.

![Diagram showing anemometer probe locations in Isis No. 4 pan.](image)

Fig. 1 - Anemometer probe locations in Isis No. 4 pan.

The technique and procedure for using hot film anemometers to measure circulation velocities in crystallisation vacuum pans have been reported by Rackemann and Stephens (2002).

Apart from quantifying the reference (base) conditions for the pan with the original stirrer, velocity data were also collected in order to validate the CFD model. The CFD model only simulated single phase flow and neglected the effects of heat transfer and ebullition. Hence, the model simulated the effects of forced circulation (i.e. the circulation flow due to the effects of the stirrer only) and did not simulate the effects of natural circulation (due to boiling).

In order to obtain velocity data for the CFD model validation, the steam supply to No. 4 pan was isolated for around 60 min when the level in the pan reached 60 t (about two thirds full). After turning the steam off, the pan was allowed to sit idle for 20 min during which time the boiling of the massecuite from the hot calandria dissipated. For the remaining 40 min the anemometers were repositioned several times to different insertion depths at each location in order to obtain velocity profiles in the different regions of the pan.
Mill data (such as stirrer amps) were collected to determine the power consumption of the stirrer motor whilst the steam was turned off. Mill data (such as the steam flow rate) was also collected to calculate HTCs whilst the pan was operating in normal mode with the steam on.

**Installation of new impeller blades**

The impeller blades of the improved design were installed in the No. 4 pan at Isis Sugar Mill for the start of the 2004 season. The design retained the four blade system and no changes were made to the hub. The design is of relatively simple construction and was manufactured quite cheaply.

Due to the restrictive size of the manhole in the pan, each of the four new impeller blades had to be constructed in two sections. The two impeller blade sections were welded together once inside the vessel.

The new impeller blades were laser cut from 25 mm thick mild steel plates and were full pen butt welded to a flange made from 36 mm thick mild steel. The leading and trailing edges were bevelled to one third of the blade thickness to improve the flow dynamics. Concentric slots were cut in the flange to provide flexibility when bolting the flange to the hub in setting the angle of the blades by ± 10 degrees. The centre of the slots in the flange corresponded to a blade angle at the hub of 25 degrees to the horizontal, which was where the blades were positioned for the 2004 season. Some details of the new stirrer are not provided because of IP issues.

**CFD model validation**

The velocity data predicted by the CFD model were compared with data obtained from Isis No. 4 pan for the original stirrer configuration. These data, together with experimental data from the 1/20th scale pan at CSIRO were used for validating the CFD models.

To demonstrate the applicability of the CFD models to simulate flows in stirred pans, Figure 2 compares the CFD model predictions for velocity at the inner probe location (location X), with the data collected from the anemometer probes. This comparison is for data gathered in the 2004 season using the new impeller geometry. The velocity data were obtained for high grade massecuites when the pan level was ~60 t. The massecuite viscosity was ~2.5 Pa.s which is considered quite low for typical high grade massecuites. Viscosity values around 5 to 15 Pa.s were expected.

The agreement is considered reasonable considering inherent errors with the circulation measurement technique, viscosity measurements and the simplifying assumptions used for the CFD modelling.
Results and observations

In 2004, with the new impeller blades installed, velocity data were collected in the same manner as in 2002 (i.e. for the massecuite quantity in the pan ~60 t and with the steam off to the calandria). Heat transfer and power data were also collected for normal operation of the pan with the steam to the calandria (on 38 pan cycles).

It was assumed the massecuite properties were similar over both seasons, however detailed analyses were not conducted. The product massecuite quality was not affected by the installation of the new impeller design but the exhaustion may have improved slightly due to the ability of the pan to produce heavier massecuites. Indications suggested that boiling times were also reduced in the order of about 10% for B massecuite strikes.

Improvement in pan circulation with the new stirrer design

The average velocities measured in 2004 were higher than in 2002 at the inner and outer locations (X and Z locations on Figure 1). Unfortunately during the trials conducted in 2004, limited data were collected at location Y as this position was mainly used for obtaining massecuite samples from the pan. The average velocities measured at location Y are lower for the 2004 season trials compared to the 2002 season trials. Table 1 shows the average velocity at each probe location during the 2002 and 2004 trials.
Table 1 - Average pan velocities at each probe location for the mass eccentric quantity in the pan at ~60 t and with the steam off.

<table>
<thead>
<tr>
<th>Mass eccentric / year</th>
<th>Average velocity at probe location X*, m/s</th>
<th>Average velocity at probe location Y*, m/s</th>
<th>Average velocity at probe location Z*, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>A mass eccentric, 2004</td>
<td>0.730</td>
<td>0.263</td>
<td>0.263</td>
</tr>
<tr>
<td>B mass eccentric, 2004</td>
<td>0.721</td>
<td>0.171</td>
<td>0.291</td>
</tr>
<tr>
<td>C mass eccentric, 2004</td>
<td>0.617</td>
<td></td>
<td>0.030</td>
</tr>
<tr>
<td>A mass eccentric, 2002</td>
<td>0.613</td>
<td>0.401</td>
<td>0.140</td>
</tr>
<tr>
<td>B mass eccentric, 2002</td>
<td>0.584</td>
<td>0.392</td>
<td>0.086</td>
</tr>
<tr>
<td>C mass eccentric 2002</td>
<td>0.503</td>
<td>0.321</td>
<td>0.021</td>
</tr>
</tbody>
</table>

* The insertion depths (as measured from the base of the pan) were:
  - Location X – 80 mm to 420 mm.
  - Location Y – 150 mm to 420 mm.
  - Location Z – 80 mm to 300 mm.

The main circulation benefit from the new impeller blades was for the increased circulation velocity measured at location Z. Since the region of the calandria closest to the outer wall of the pan has a large proportion of the calandria tubes, an improvement in circulation velocity at location Z greatly increases the volumetric flow, and the velocity of mass eccentric entering the tubes, in this region. This is expected to positively impact on the heat transfer performance of the pan.

The information in Table 1 is based on the arithmetic average velocity measured at each location for the mass eccentric quantity in the pan at ~60 t and with the steam turned off. For these conditions the circulation in the pan was caused primarily by the motive forces imparted by the stirrer. The average stirrer speed used in the 2004 trials was slightly higher than in 2002 (27 r/min in 2004 compared with 25 r/min in 2002).

The main benefits to circulation provided by a stirrer are realised towards the end of a pan strike when the viscosity of the mass eccentric is greatest and the boiling level is highest. Unfortunately the benefits could not be characterised under these conditions as it would be inadvisable to turn the steam off towards the end of the strike to measure the circulation caused by the stirrer only. It is considered likely that, at the pan full condition, the increase in velocity under the calandria in the outer region would have been greater than the increase shown in Table 1.

**Improvement in heat transfer with the new stirrer design**

Efficient utilisation of the heating surface area in the calandria is important in order to provide good heat transfer to the mass eccentric. The overall HTC for a pan gives an indication of the effectiveness of heat transfer. The description below outlines how the heat transfer was calculated.

The latent heat and temperature of the steam in the calandria were interpolated from steam tables correlations to the measured calandria pressure, based on the assumption that the supply steam is saturated within the calandria. Using the measured steam flow rate to the pan and assuming all steam condenses, the heat flux \( Q_{heat} \) is determined by,

\[
Q_{heat} = \lambda \times M_{steam}
\]  

(5)
where $Q_{\text{Heat}}$ is the heat flux (W), $\lambda$ is the latent heat of condensation of the steam (J/kg), and $M_{\text{steam}}$ is the mass flow rate of the steam (kg/s).

The overall HTC is defined as,

$$ U = \frac{Q_{\text{Heat}}}{A \times \Delta T_{\text{eff}}} $$

(6)

where $U$ is the overall HTC (W/m²/K), $A$ is the area available for heat transfer (m²), and $\Delta T_{\text{eff}}$ is the effective temperature difference (K).

The effective temperature difference is defined as the difference in temperature between the boiling massecuite and the saturated steam within the calandria. The boiling temperature of the massecuite in the calandria tubes is estimated from the temperature of the saturated vapour at the operating pressure in the head space with the addition of a boiling point elevation (such as used by Batterham and Norgate, 1975) to account for the massecuite properties.

The HTCs for A, B and C massecuites were calculated from data collected in 2004 and compared with the HTCs calculated from data collected in 2002. These HTC values are shown in Table 2. For the new stirrer, the improvement in average HTC for the strike when processing B massecuite was 16%, and 40% when processing C massecuite. No comparison can be made for A massecuite as no HTC data were obtained in 2002. The largest relative increase in HTC was for C massecuites at the end of the heavy up, i.e., when the pan was full and the massecuites were most viscous.

Table 2 – HTC data collected during the 2002 and 2004 crushing seasons.

<table>
<thead>
<tr>
<th>Massecuite / year</th>
<th>Average HTC over strike, W/m²/K</th>
<th>HTC at the start of heavy up, W/m²/K</th>
<th>HTC at the end of heavy up, W/m²/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>A massecuite, 2004</td>
<td>437</td>
<td>415</td>
<td>358</td>
</tr>
<tr>
<td>B massecuite, 2004</td>
<td>398</td>
<td>358</td>
<td>291</td>
</tr>
<tr>
<td>C massecuite, 2004</td>
<td>243</td>
<td>240</td>
<td>130</td>
</tr>
<tr>
<td>B massecuite, 2002</td>
<td>342</td>
<td>318</td>
<td>259</td>
</tr>
<tr>
<td>C massecuite, 2002</td>
<td>173</td>
<td>157</td>
<td>11</td>
</tr>
</tbody>
</table>

With the incorporation of the new impeller blades in Isis No. 4 pan, the pan operators had greater difficulty discharging the contents of the pan. This was most evident when processing C massecuites. This is because the improved circulation and heat transfer in 2004, especially over the final stages of the C strike, enabled increased massecuite exhaustion and the production of heavier massecuites. The load on the new stirrer was substantially higher than for the original stirrer during heavy up of C massecuite.

**Power consumption with the new stirrer design**

Power data were collected for No. 4 pan during several strikes in the 2004 season for normal operation of the pan with the steam on. The power consumption increased for all massecuite types during the course of the strike and especially at the end of C massecuite strikes, as shown in Table 3.

Isis Mill changed the drive for the stirrer motor in 2004 from an ACS 600 to an ACS 800. After the drive was changed, the Bailey logic was also altered. In 2004, the Bailey
presented current load on the motor from 0-151 amps. Unfortunately, some uncertainty exists for the range used to record the motor amps in the 2002 season and no power data for the original stirrer are presented. Based on the increased circulation velocity of massecuite and increased viscosity at pan drop, the power consumption at the end of the strike is thought to be substantially higher for the new stirrer.

**Table 3** – Power consumption of Isis No.4 pan stirrer during the 2004 season trials.

<table>
<thead>
<tr>
<th>Massecuite</th>
<th>Average* power consumed over the strike, kW</th>
<th>Power consumed at the end of the strike, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>A massecuite</td>
<td>9.9</td>
<td>15.5</td>
</tr>
<tr>
<td>B massecuite</td>
<td>11.2</td>
<td>17.1</td>
</tr>
<tr>
<td>C massecuite</td>
<td>17.3</td>
<td>68.1</td>
</tr>
</tbody>
</table>

* Time average over entire strike and averaged for several strikes.

The stirrer motor for Isis No. 4 pan provides installed power of 1.5 kW/m³, which conforms to the rule of thumb for C massecuites.

The power data from 2004 for the conditions at the 60 t level and for the heavy up conditions are plotted against $\mu N^2D^3$, the functional expression of Equation 4, in Figure 3. Predicted power consumption values from the CFD models are also shown in Figure 3. The viscosity values were estimated based on typical fluid conditions during A, B and C massecuite strikes using the correlation described by Broadfoot et al. (1998). There is some uncertainty in the value of the power factor that should be applied to the data and this will affect the power results in Figure 3. A power factor of 0.85 has been applied to all the data.

![Figure 3 - Correlation between stirrer speed, viscosity and power consumption for the 2004 stirrer design during the trials at Isis Mill.](image)

The CFD predictions for power consumption overestimate the power consumption when compared to the factory data. However, the CFD model does not account for the reduced drag and hence reduced load on the stirrer caused by natural circulation. These effects would be substantial. Rackemann et al. (2004) estimated that, for stirred high grade pans, the motive
power generated within the massecuite from ebullication ranges between 85% of the total motive power at the start to ~45% at the end of the strike. For low grade strikes in stirred pans the motive power due to ebullication ranges between 60% at the start to ~10% at the end of the strike.

Figure 3 shows the rule of thumb relationship for power based on a proportionality constant of 0.0576, which was developed for a similar stirrer design (pitched blade turbine impeller) but with lower solidity (Bentley et al., 1988) than the new impeller installed at Isis Mill. Figure 3 shows linear relationships to define the proportionality constant for the power data for heavy up (constant of 0.1022) and for the data at the 60 t level (constant of 0.1339).

The new stirrer has a larger power requirement for the same stirrer speed, diameter and viscosity of massecuite than the ‘rule of thumb’. This is because of the increased solidity and increased angle of the blades.

For design purposes the installed power and rotational speed must be selected to suit the pan discharge conditions, as this defines the maximum power consumption of the stirrer. If desired, faster speeds can be employed during the run up when the massecuite viscosity is lower. It is important that a conservative value for the proportionality constant is used to define the power consumption at the pan discharge condition. A constant of 0.14 encompasses most of the data obtained for the new impeller (refer Figure 3).

In specifying the parameters for an installation of the new stirrer design, the maximum stirrer speed would be selected to ensure the installed power of the stirrer is 1.0 to 1.2 kW/m³ for A and B massecuite and 1.5 to 1.6 kW/m³ for C massecuite. The stirrer speed at the pan discharge condition should provide a safety factor to ensure the stirrer will still operate under adverse conditions (e.g. when processing viscous massecuites associated with stale cane).

The data in Figure 3 for power consumption at the 60 t level in general lie above the proportionality relationship for the heavy up data. At the 60 t level, Re_{stirrer} is typically 40-4200 which is in the transitional turbulence region.

**CFD modelling to predict changes in performance**

Previous research has shown the CFD model can be used to predict the performance of stirred pans when no steam is applied to the pan, albeit for a few small differences due to the simplifying assumptions of the model. Caution should be taken when applying the CFD model to normal pan operation involving both mechanical and natural circulation.

Modelling studies were undertaken (with no steam applied to the pan) for the configuration of the new stirrer installed in Isis No. 4 pan. The studies included changes to:

1. Impeller blade angle;
2. Pan bottom geometry; and
3. Flared region immediately above the calandria.
The CFD modelling was conducted for high grade and low grade strike conditions for the investigation of the impeller blade angle and for only high grade strike conditions for changes to the pan geometry. The CFD modelling found that:

- Reducing the angle of the impeller blades relative to the horizontal (from 25 degrees to 20 degrees) improved the power efficiency, \( Np/NQ \), of high grade strikes by only a small amount (3.3%). The impeller blade angle of 25 degrees used in Isis No. 4 pan during 2004 gave the optimum power efficiency for low grade strikes;

- Changing the vertical distance between the apex of the bottom cone and the bottom tube plate (reducing the clearance under the calandria from 550 mm to 400 mm) improved the power efficiency of high grade strikes by 5.0%. This reduction in the clearance under the calandria changed the flow ratio\(^1\) from 1.04 to 0.79;

- Having a flared region immediately above the calandria produced a slight improvement in the power efficiency of high grade strikes for the same boiling level. No simulations were conducted on low grade strike conditions.

By taking advantage of a small improvement in power efficiency of the stirrer, small but beneficial improvements in circulation can be achieved for the same power consumption. The increased circulation increases the HTC of the pan and the maximum evaporation rate. Increased throughput for the pan, through reduced cycle times, may result.

A comparison of the CFD predictions of \( Np/NQ \) values for the original and new impeller designs, for different impeller blade angles and pan geometries are shown in Table 4. These data are for motive forces imparted by the impeller only i.e. no circulation or change in power due to ebullition is included.

**Table 4 - Comparison of predicted \( Np/NQ \) values for the original impeller and for the new impeller under different configurations.**

<table>
<thead>
<tr>
<th>Impeller and pan specifications</th>
<th>( Np/NQ ) values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High grade strike conditions</td>
</tr>
<tr>
<td>Original impeller design in the Isis No. 4 pan</td>
<td>8.17</td>
</tr>
<tr>
<td>New impeller design – 15 degree blade</td>
<td>7.39</td>
</tr>
<tr>
<td>New impeller design – 20 degree blade</td>
<td>7.19</td>
</tr>
<tr>
<td>New impeller design – 25 degree blade</td>
<td>7.44</td>
</tr>
<tr>
<td>New impeller design – 35 degree blade</td>
<td>8.31</td>
</tr>
<tr>
<td>New impeller design – Reduction in clearance</td>
<td>7.07</td>
</tr>
<tr>
<td>New impeller design – Increase in clearance</td>
<td>7.67</td>
</tr>
<tr>
<td>New impeller design – Non-flared pan design</td>
<td>7.40</td>
</tr>
</tbody>
</table>

\(^1\) The flow ratio is the ratio of the vertical area for massecuite flow below the downtake wall to the cross-sectional area of the downtake and is a method used by the industry for specifying the pan bottom shape and clearances under the calandria.
Discussion and conclusions

SRI designed a new impeller for batch centre well pans based on the results of pilot scale investigations and CFD modelling. The new impeller design was installed in Isis No. 4 pan for the 2004 season.

The new design provided the following benefits to the performance of the pan:

- Increased circulation. The flow rate of massecuite through the outer regions of the calandria was substantially increased. The CFD models also predicted substantial increases in the velocity of massecuite exiting the calandria tubes in this region; and
- Increased heat transfer efficiency. The HTC for B massecuites increased by 16% and the HTC for C massecuites increased by 40%.

The new design of impeller consumes more power than conventional impeller designs used in the Australian sugar industry (for the same rotational speed and diameter). However, the impeller exhibits improved power efficiency and operation to the same power input (at reduced speed) achieves increased volumetric flow of massecuite.

The CFD models indicate that reducing the impeller blade angle to 20 degrees when processing lower viscosity massecuites (high grade strikes) can increase the power efficiency of the stirrer by 3.3%. For higher viscosity massecuites (low grade strikes) an angle of 25 degrees as currently installed, is ideal. For pans that boil different massecuites it is recommended that the impeller blade angle is set to suit the heavier (more viscous) massecuite.

The modelling found that the bottom shape of the pan influences the stirrer power efficiency. Among the options to change the bottom of the pan, reducing the clearance under the pan by changing the vertical position of the apex of the conical bottom showed the greatest improvement to the power efficiency of the stirrer (by 5.0%). This clearance needs to be carefully selected in designing a stirred pan in order to maximise the benefit of the stirrer.

CFD modelling indicated that including a flared region above the calandria marginally improved the stirrer power efficiency for high grade strikes.

The new impeller design is suitable for retrofitting into existing batch pans. It is cheap to install onto existing drives and has been shown to provide substantial benefits to circulation rate and heat transfer. The most important benefit from the new impeller design is the increased flow of massecuite to the outer regions of the calandria. Increased productivity of the pan with the new impeller is expected to result.

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