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SECONDARY RECOVERY OF BITUMEN USING JAMESON DOWNCOMERS

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ABSTRACT

A full-scale prototype of "Jameson Downcomer" technology has been installed and tested on a Tailings Oil Recovery (TOR) vessel in Syncrude's Mildred Lake extraction plant. Jameson Downcomers are a type of mineral flotation equipment used in the coal industry that Syncrude has extended to the recovery of secondary bitumen in the oil sand extraction process. The TOR vessels are currently being operated as single-gravity separation vessels, in series with the Primary Separation Vessels (PSV's). We have developed a model to differentiate between "floating" and "non-floating" bitumen in the PSV's, and then applied it to verify that the current TOR performance only captures the "floating" bitumen by simple separation. The existence of "non-floating" bitumen provides an opportunity for recovery enhancement by means of the Jameson Downcomers. To achieve bitumen recovery enhancement, middlings slurry is withdrawn from the TOR vessel, and passed through a number of parallel Jameson downcomers, within which the slurry is accelerated to a high-velocity free jet, and impinged upon the slurry surface inside the downcomer, in the presence of air. The aerated slurry is returned to the middlings zone inside the TOR, resulting in an incremental recovery improvement of bitumen in the TOR. The operation of the downcomers is thought to produce suitably small air bubbles for the flotation of bitumen, either by fluid shearing during the slurry jet impingement, and/or by micro-bubble nucleation. This full-scale prototype design has met or exceeded the recovery expectations of the original Research piloting, recovering at least 40% of the non-floating bitumen. In Syncrude Extraction, this provides high business value by a separation efficiency gain achieved with modest expenditure. As well, the system has demonstrated excellent operability and maintainability.

KEYWORDS

Bitumen, oilsand, Jameson, downcomer, flotation

INTRODUCTION

Syncrude Overview

Syncrude Canada Ltd. is one of the largest producers of crude oil from oil sands. Our crude oil production facility has the capacity to produce over 15% of Canada's total oil requirements. To do this, we surface mine oil sand, extract the raw oil known as bitumen from the sand using water-based processes, and upgrade that bitumen into sweet light crude oil by fluid coking, hydro processing, hydro treating and reblending.

Our final product, Syncrude Crude Oil (SCO), is sent by pipeline to three Edmonton area refineries and to pipeline terminals which ship it to other refineries in Canada and the United States.

The Syncrude operation is comprised of four major technology areas: Mining, Extraction, Upgrading and Utilities. As well, Syncrude invests more than $40 million annually in science and technology, and is among the top 50 companies in Canada for Research and Development (R&D) investment. Syncrude holds 21 active Canadian and U.S. patents.

Extraction Recovery Opportunity

Syncrude's Plant 5 Extraction at the Mildred Lake operating site consists of simple gravity separators, for primary and secondary flotation of bitumen, as depicted in Figure 1. Primary vessels include four large Primary Separation Vessels (PSV's) and two smaller Additional Settling Area Vessels (ASA's), all configured in parallel. These vessels are fed from a common source of conditioned oilsand slurries, prepared in upstream hydrotransport or Tumbler processes. Bitumen froth product is produced from these primary vessels, and sent downstream for further processing.

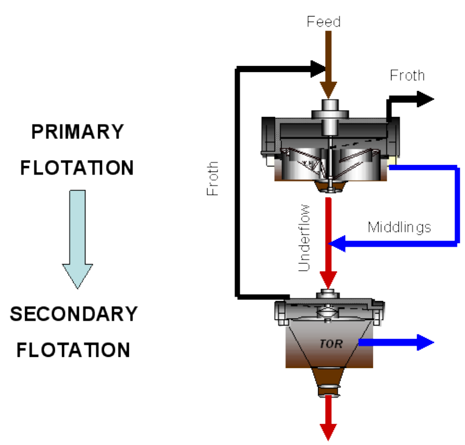

Figure 1 - Simplified Process Layout for the Syncrude Mildred Lake Extraction Plant

Middlings and underflow streams from the PSV's and ASA's are re-processed in the four Tailings Oil Recovery Vessels (TOR's) for secondary bitumen recovery. Bitumen froth from the TOR vessels is recycled to the PSV feed for froth quality upgrade, and recovered as primary froth.

The TOR vessels are currently not equipped with any aeration device and operated only as simple gravity separators. The TOR vessels lack the capability of active shearing and aeration needed to recover all the bitumen contained in the PSV middlings and underflow streams. This represents an opportunity for bitumen recovery improvement.

Bitumen Floatability Model

A model was developed for quantifying the floatability of bitumen, applied to secondary recovery. Bitumen that is not recovered in the primary vessels, and thus reporting to either the withdrawn middlings or underflow streams, was divided into two categories:

1) Floating Bitumen
2) Non-Floating Bitumen

"Floating bitumen" is that bitumen which occurs as aerated bitumen droplets which ideally should have floated in the primary vessels, but was simply missed. Some floating bitumen droplets will be captured in the withdrawn middlings stream as their buoyancy is not sufficient to overcome the drag caused by the velocity of the exiting fluids. Virtually all this aerated bitumen would be expected to float given another chance in a downstream gravity separator. Also, the floating bitumen would be expected to be found only in the withdrawn middlings stream – the modeling assumption is that none of it is found in the withdrawn underflow stream.

"Non-floating bitumen" is that bitumen not recovered in the primary vessels because of its inherent properties, for example: droplets are too small and/or inadequately aerated and/or laden with solids or slime coating. Significant portions of this bitumen can potentially be recovered in secondary processing, if given adequate mixing/shearing and addition of fine air bubbles that promote droplet coalescence and aeration. The non-floating bitumen is modeled to be equally distributed throughout the water phase, occurring in both the withdrawn middlings and underflow streams.

The relative proportions of floating and non-floating bitumen in the secondary feed may be computed by Equation (1), given the bitumen mass rates ("MBIT"), and the bitumen and water mass assays of primary middlings (mids) and underflow (UF) streams. This equation depends only on mass continuity, and the above modeling assumptions.

$$\text{Floating Bitumen (\%)} = (b_{mids} - b_{UF}) / (b_{mids}) * (MBIT_{mids}) / (MBIT_{mids} + MBIT_{UF}) * 100\% \quad (1)$$

$$\text{Where:} \quad b = (\%\text{bitumen}) / (\%\text{bitumen} + \%\text{water}) \quad (1b)$$

The floatability model was evaluated by comparison to the measured TOR bitumen recoveries in the operating plant, as shown in Figure 2. We would expect the TOR vessels, operated as simple separators, to only recover the "floating" component of the bitumen in the secondary feed. The remarkably close comparison to actual recoveries, verifies that the modeling approach is valid. This confirms that there is a significant opportunity for secondary bitumen recovery improvement in the current plant flow sheet.

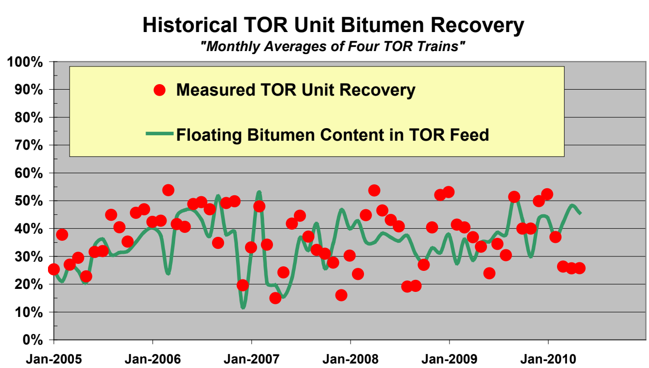

Figure 2 - Validation of the Bitumen Floatability Model

Jameson Downcomer Technology

The Jameson downcomer technology is named after its inventor, Dr. Graeme Jameson, from the University of Newcastle, Australia. The typical use of Jameson technology is in the Australian mining industry for flotation of washed fine coal particles.

The heart of the technology is the "downcomer", as illustrated in Figure 3. Energy is introduced by pumping the mineral slurry and accelerating the flow through a restriction, called the slurry lens orifice. This creates a plunging jet which impinges on the liquid surface within the downcomer and disperses the energy into liquid-to-liquid shear.

At the same time, air is passively induced by the momentum of the jet, and formed into suitably small air bubbles for flotation. Mechanisms of bubble formation probably include both turbulent shearing due to the jet impingement, and micro-bubble nucleation due to the jet pressure drop.

The downcomer cylinder contains the shear zone, providing maximum opportunity for air-to-mineral contact, and coalescence of aerated mineral droplets. Multiple downcomers are usually configured in parallel, discharging into the middle slurry zone beneath the top froth layer of a passive separator, for flotation of a mineral froth.

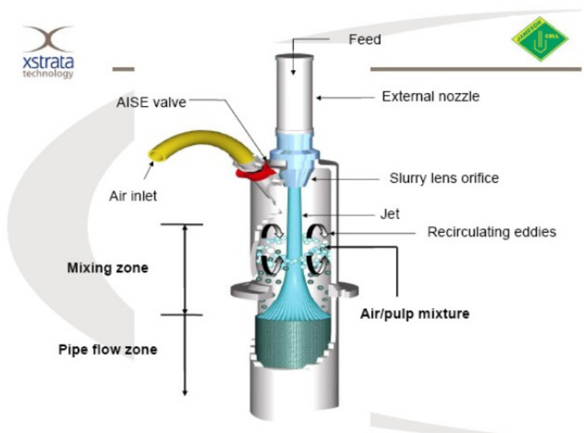

Figure 3 - Jameson Downcomer

Application to Secondary Bitumen Flotation

Continuous piloting studies with Jameson downcomers were conducted at Syncrude Research to explore the application to bitumen flotation. There were several key findings:

- As bitumen is naturally hydrophobic, it does not require extensive surface chemistry modifications for flotation, as in the case of typical mineral flotation. We found that a substantial portion of the non-floating bitumen could be recovered using the downcomers.
- The levels of air addition for secondary bitumen recovery were much less (typically 6 vol%) compared to standard levels for fine coal flotation (typically 50 vol%). The lower air levels for bitumen reflected the lower mass content of bitumen in the feed stream and the affinity of bitumen to air bubbles. There is the need to avoid over-frothing the bitumen thereby floating too many of fine solids along with the bitumen.
- The best material selection for the downcomers was stainless steel, to avoid corrosion while also avoiding bitumen adherence to downcomer walls.
- The presence of large amounts of coarse solids in the TOR feed stream was found to inhibit the aeration in the downcomers. In contrast, processing of recycled TOR middlings through the downcomers enabled a more efficient means of recovering the bitumen, and also a practical means

of retro-fitting the downcomers to the existing TOR vessels. With recycled TOR middlings, both the control and relative amount of slurry through the downcomers could be accomplished independently of the TOR throughput. The de-coupling of these two flow processes provides a key operational advantage. This innovation is protected by Canadian Patent CA2577743 (Siy, Spence, & Neiman, 2011). The general arrangement is as shown in Figure 4.

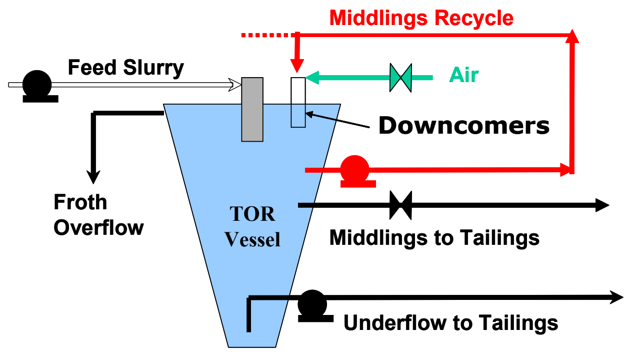

Figure 4 - Application of Jameson Downcomers to the TOR Process

- The process benefits from operation of downcomers could be scaled by the "motive momentum" of the jet flow, as defined in Equation (2):

Motive Momentum (m/s) = Jet Velocity (m/s) * Middlings Recycle Ratio (2)

Where: Middlings Recycle Ratio = (Total Recycled Flow) / (Middlings Feed Flow to TOR) (2b)

This concept had been developed in previous studies with TOR middlings eductors (Kwong & Tran, 1992). It is fundamentally reasonable that the benefit from an aeration eductor would increase with increasing jet velocity. The absolute jet velocity would be expected to scale across a wide range of equipment sizes, in the same way as turbulent eddy sizes scale with absolute velocity. It is also reasonable that the benefit would increase with increasing amount processed, i.e. with increasing recycle ratio.

When the model was applied to data generated by Research pilot studies with downcomers, a scaling relationship was derived, as shown in Figure 5. The process benefit, expressed in terms of "recovery of non-floating bitumen" is shown to increase with increasing motive momentum, then level off at some point, in similar fashion to that observed by Kwong and Tran (1992).

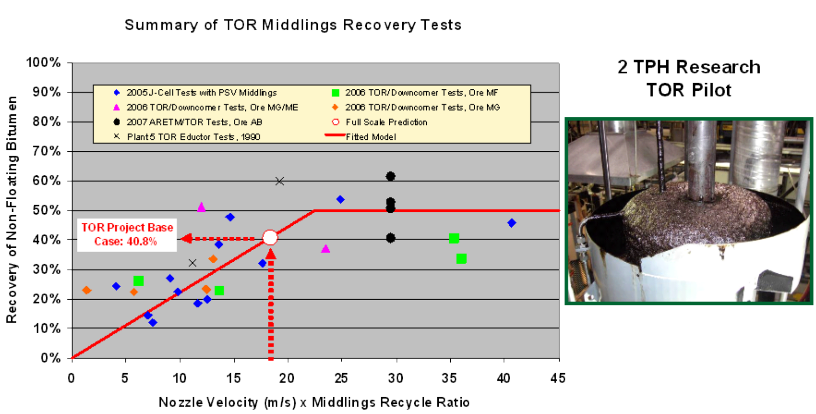

Figure 5 - Modeling of Downcomer Process Benefit, from Pilot Studies

Simulation modeling of our application was completed by the vendor, as shown in Table 1, to help guide an experimental design. Typical jet velocities in other downcomer applications are in the range of 12-15 m/s. Also, from previous experience we expect that bubbles in the size range of 300-500 microns would be most suitable for flotation of our non-floating bitumen droplets. From Table 1, a total flow of 900 L/s, through eight downcomers with 100 mm lens diameters, is shown to be in a reasonable range.

Taking the above specifications as a base case design, the model in Figure 5 predicted the non-floating bitumen recovery to be approximately 40%. This value served as a benchmark to "meet or exceed" in a full-scale implementation on the TOR vessels.

Table 1 – TOR downcomer modeling (Xstrata Technology)

No. of downcomers	8	8	8	8	8
Recycle Flow, (L/s)	900	900	900	900	900
Downcomer Diameter, (m)	0.5	0.5	0.5	0.5	0.5
Lens Diameter, (mm)	75	100	125	150	200
Jet Velocity, (m/s)	25.5	14.3	9.2	6.4	3.6
Bubble Diameter, (μm)	338	530	752	1002	1585

EXPERIMENTAL

Equipment

A full-scale test prototype of Jameson downcomers was installed on TOR Vessel #4 in Syncrude's Plant 5 Extraction. General layout was as shown in Figure 6.

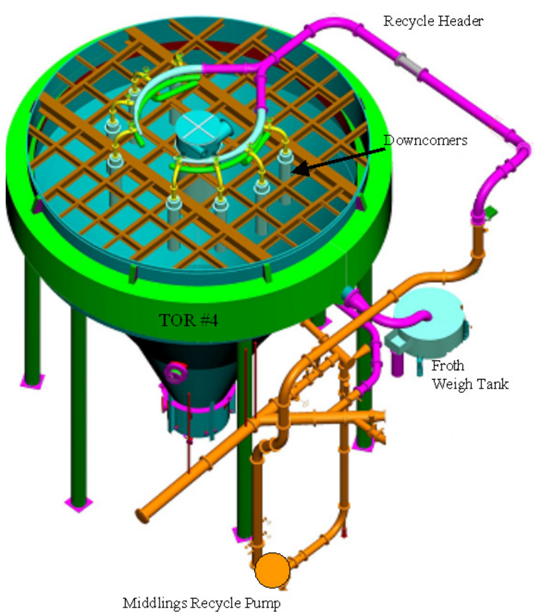

Figure 6 - Full-Scale Test Prototype Details

The experimental system consisted of the following:

- An internal header and 16" piping for withdrawing middlings from the TOR to the recycle pump.
- A middlings recycle pump, Warman Model 450 STL 5-Vane Closed, 300 HP.
- Eight parallel downcomers, supplied by Xstrata Technology, Model F16765/8-M-500-S-SX-1-M, of 0.5m diameter, and 3m length, with slurry lens diameters of 100 mm, 125 mm, or 150 mm.

- An air distribution system to control air to each downcomer inlet.
- An instrumented batch weigh tank, to measure the mass rate of TOR vessel overflow.
- Provisions for sampling and flow measurement, to assess the TOR vessel performance.

Test Program

A test program was conducted during 2010, with the main objective of proving the secondary recovery benefit of downcomers at full-scale conditions, which had been predicted from Research studies. The test strategy was to operate the TOR vessel with many iterations of downcomers "ON" and "OFF", in adjacent time periods, and compare the process performance results between those time periods, including: TOR unit recovery, TOR bitumen losses, TOR froth quality, and PSV froth quality.

A total of approximately 50 tests were completed with ON/OFF time periods of 1 hour each, including 14 tests using the Froth Weigh Tank for measurement of TOR froth rates. In addition, a total of approximately 3½ months of shift operating tests were completed with ON/OFF time periods of 12 hours each. This included 1 week of tests measuring the impact of TOR froth recycle on PSV froth quality.

During downcomer operation, the following process conditions were varied:

- Slurry processability conditions: random, over a wide range.
- Downcomer Air Rate: 0-6 vol%
- Number of downcomers operated: 8, 6, 4, or 2
- Slurry Lens Size: 100 mm, 125 mm or 150 mm
- TOR #4 middlings recycle rate: 500-700 L/s

RESULTS AND DISCUSSION

TOR Recovery Performance

Figure 7 shows the compilation of all available data comparing the bitumen content of the TOR underflow stream between adjacent conditions of Downcomers "OFF" versus Downcomers "ON". The bitumen content of the TOR underflow stream is a strong inverse marker of TOR bitumen recovery. For example, if the downcomers had no impact, we would expect to see data scattered around the equality line. However, the data in Figure 7 shows that losses were consistently reduced when the downcomers were "ON", and often by very substantial amounts.

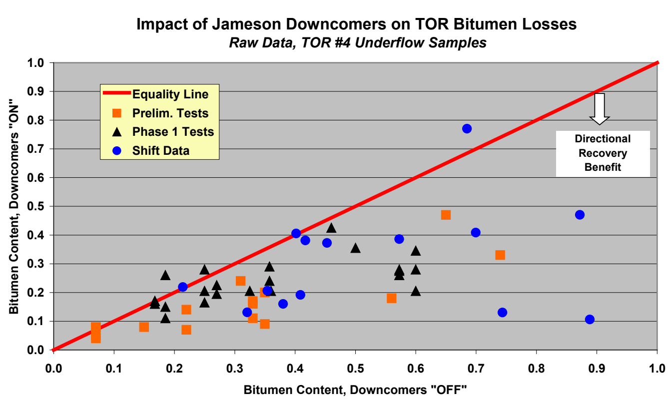

Figure 7 - TOR Bitumen Loss Results

Figure 8 summarizes the results from all tests using the Froth Weigh Tank. In fourteen tests completed, the TOR bitumen production always increased when the downcomers were "ON". This data provided the most confident evidence of process benefit, because the production rates were directly measured.

The benchmark of 40% recovery of non-floating bitumen, previously established from Research tests, was matched on average by the prototype operation. This was despite a shortfall in the attainable recycle rate, the recycle pump was limited to about 700 L/s compared to 900 L/s used in the modeling. Therefore, opportunity exists for upgrading the process benefit in a permanent commercial design.

The results from tests #2 and #3 provided particular encouragement for the potential value of the technology. The largest absolute increases in bitumen production were experienced during the periods of highest bitumen loading to the secondary system, i.e. just when needed the most.

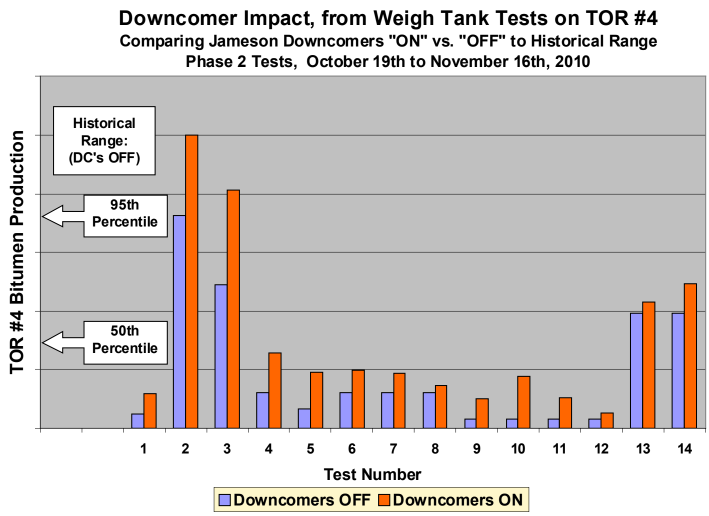

Figure 8 - TOR Bitumen Production Results

The downcomers were configured and operated in the same way for all the data shown in Figure 8 (8 downcomers, 100 mm lens diameters, 700 L/s recycle rate, 6 vol% air), and yet the results varied widely. This illustrates the over-riding influence of the feed conditions on the performance, which is typical of a secondary oil sand Extraction process.

From earlier tests where the number of downcomers and lens diameters were varied through a wide range, we were able to confirm a positive correlation between downcomer motive momentum and the process benefit. These results are shown in Figure 9. Use of the smallest lens diameter (100 mm) produced the largest process benefit, which was consistent with the modeling predictions.

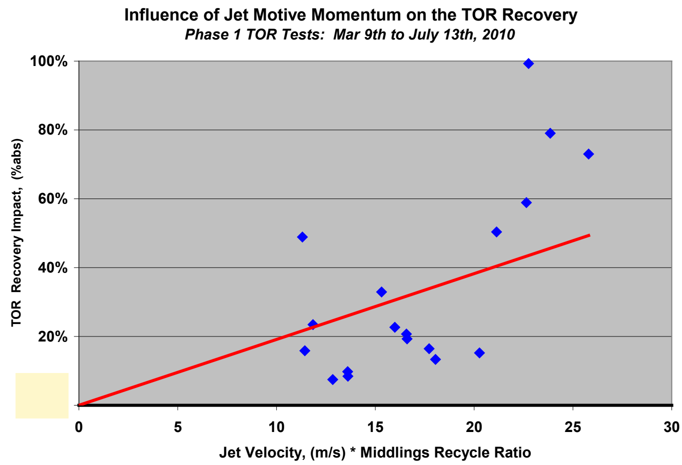

Figure 9 - Modeling of Downcomer Process Benefit, from Full-Scale Studies

PSV Froth Quality Impact

Figure 10 shows results for PSV froth quality, as the TOR downcomers were iterated "ON" and "OFF" in 12-hour periods, over several months. The increased amounts and changing composition of TOR froth recycled to the PSV did not appreciably affect the bulk composition of PSV froth. Similar "nil" impacts were observed in the fines contents and d_{50} particle sizes of PSV froth.

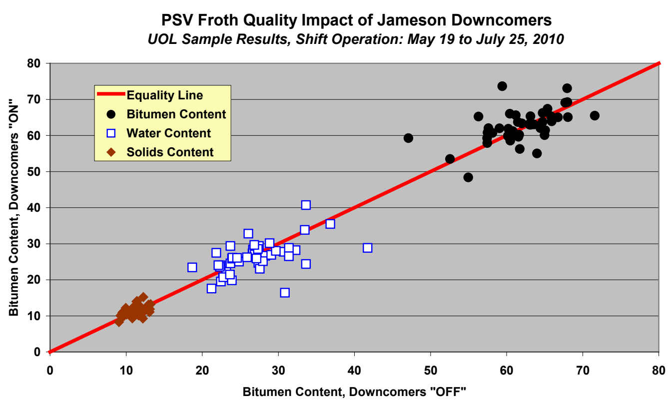

Figure 10 - PSV Froth Quality Impact

Operability and Maintainability

Operability of the downcomer system was, overall, very good, with no key issues identified. Controls of the middlings recycle flow and air flow were done manually, at a fixed operating point. Process personnel readily accepted the system for routine operation.

Maintainability of the downcomers was also very good. Slurry lenses or downcomers could be removed without vessel entry, providing a key advantage. There was no noticeable wear on any of the slurry lenses, during approximately 1500 hours of operation during the test program.

CONCLUSIONS

The technology of Jameson downcomers, from the Australian coal industry, has been successfully extended to recovery of secondary bitumen in Syncrude's Mildred Lake oil sand extraction process. The downcomers may be retro-fitted to existing Tailings Oil Recovery (TOR) vessels, and are best configured to process recycled TOR middlings. This provides a practical and efficient means of recovering the previously "non-floating" bitumen, not recovered in the upstream primary separation vessels. The process benefit may be scaled by the "motive momentum" of the downcomer jets (jet velocity multiplied by the middlings recycle ratio). Substantial amounts (40% or greater) of the non-floating bitumen were recovered by a prototype design, with opportunity for improvement by increasing the recycle ratio. The primary froth quality does not appear to be affected by the increased amounts of secondary froth recycled to the primary vessels.

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