The Impact Wear Behavior of Large Rocks on Slurry Pump Materials and Equipment.

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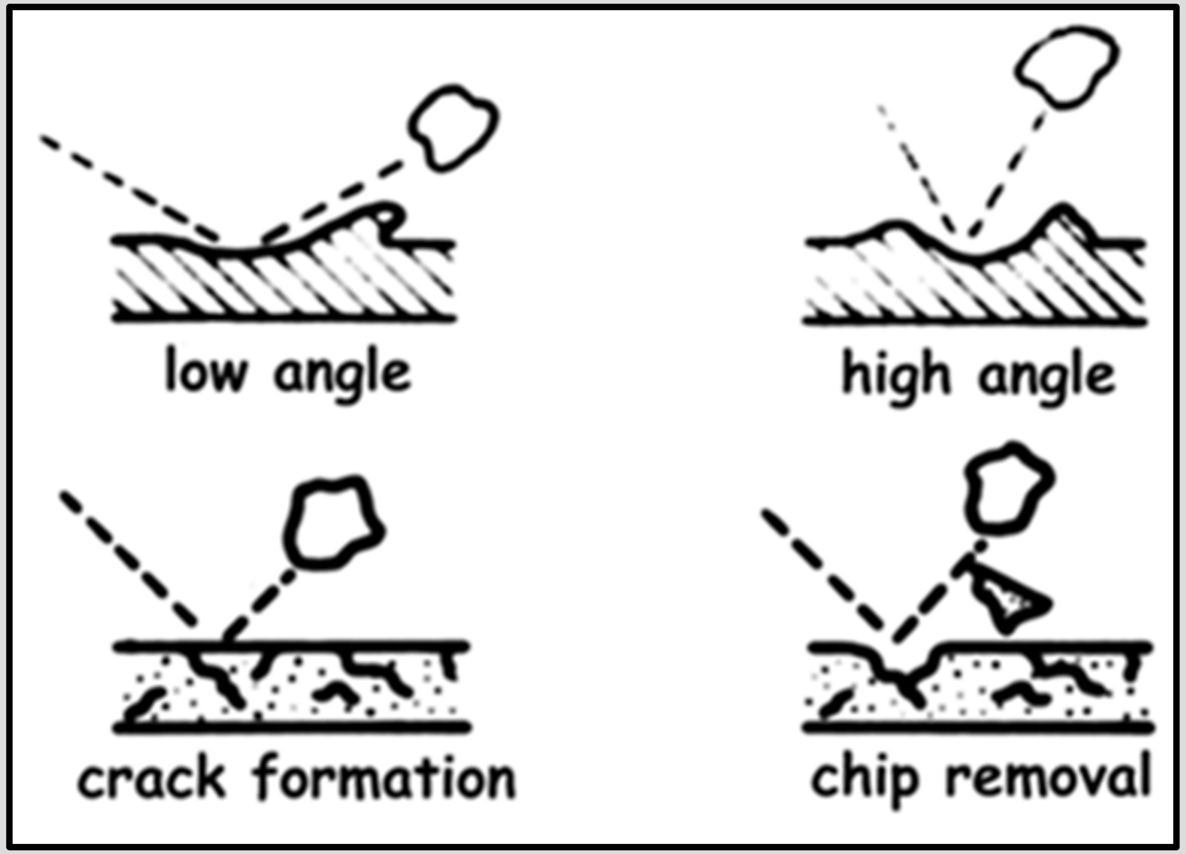
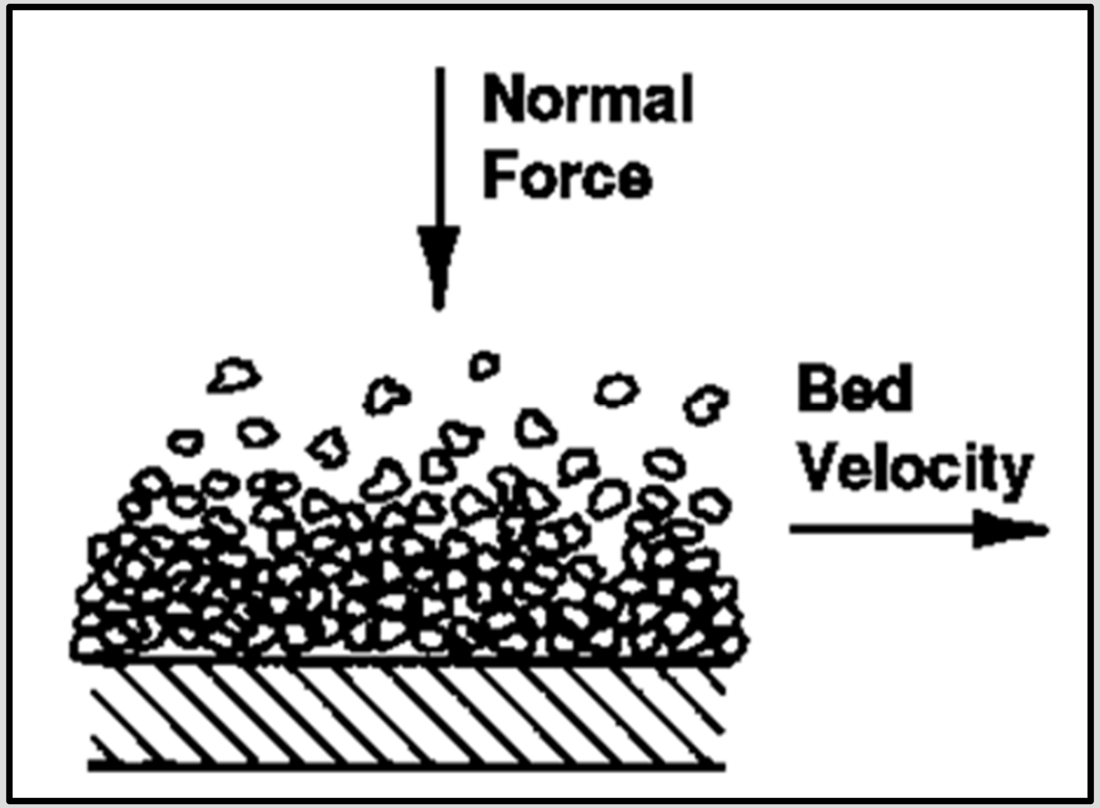


Impact wear



Sliding bed wear

Erosive Wear Mechanisms

Impact and Sliding

- Impact and Sliding wear are the primary modes of erosion in slurry handling equipment.
- Impact wear dependent on:
  - Particle velocity and mass.
  - Other particle properties.
  - Material properties.
- Sliding wear dependent on:
  - Force and velocity of the sliding bed.
  - Particle size and abrasivity.

Typical Wear Performance

Sliding Wear

- Sliding wear is the the most common mode of wear in slurry pumps.
- Typical “sand dune” appearance of worn surfaces.
- Dominates wear performance in most cases, even in the slurry pump impeller.

Large river rock dredge

Oil sands hydrotransport

Typical Wear Performance

Impact Wear

- Impact wear is more limited in slurry pump applications.
- Typical “frosted” appearance.
- Wear back of the impeller vane the most usual problem.
- Leads to loss of head as vane length and overlap are lost.
- Most common in unprocessed slurry streams, such as dredging and hydrotransport of as-mined material.

Application	Solids type	Solids Top size	Slurry SG	Comment
Cutter dredge service	Bedrock	up to 500 mm	1.2 – 1.4	Concentration of coarse solids is high.
River rock dredging	River rock	200 to 300 mm	1.2 – 1.4	Solids are rounded.
Oil Sands hydrotransport	Silica rock and oil sand lumps	125 to 150 mm	1.5 – 1.6	Bi-modal solids size distribution (sand + lumps). Lumps approx. 2% concentration by volume.
Coarse grinding mill discharge	Metal ore	> 75 mm	1.3 to 1.6	Broad solids size distribution, however, solids SG may be higher than 2.7.

Table 1. Applications where impact wear is often seen to limit slurry pump parts life.

Typical Wear Performance
Impact Wear Dominance

- Usually occurs only with significant topsize > 75 mm.
- Limiting size may be smaller for more dense solids (i.e. metal ore concentrates).
- For accurate wear prediction in these cases, experimental data on impact wear with large solids is needed.

Design of the Experiment

Some questions:

- How do various materials rank against each other under heavy impact?
- Do the wear mechanisms undergo a significant change with large solids?
- Are some materials unsuitable, due to limited strength or toughness?
- How important is material strength relative to hardness?
- Does the theoretical, third power relationship between velocity and impact wear hold true?

Design of the Experiment

Solids

- Locally obtained granite “rip-rap”.
- Hand sorted through a 6”x6” (150mm) grizzly.

Design of the Experiment

Flow Passage

- Experiment consisted of 2” (50 mm) bars of wear material inserted vertically into a 20” (508 mm) pipeline.
- Five samples were run simultaneously, spaced at intervals of 15 ft (4.5 m).
- Slurry flow velocities:
  - 20, 25, 30 and 33 ft/s
  - (6.1, 7.6, 9.1 and 10 m/s)

Design of the Experiment

Wear Test Samples

A. High chrome white iron
B. Chrome-moly white iron
C. Hypereutectic, high carbide content, white iron
D. GIW WD29G® white iron (w/ high strength, lower hardness)
E. GIW Endurasite® white iron (w/ increased hardenability)
F. 80 % tungsten carbide insert
G. 88 % tungsten carbide insert
H. Laser cladded tungsten carbide hard facing
I. 4140 low alloy steel

Test Setup and Execution

Pump and Driver

- GIW TBC 57 slurry pump.
- 28” suction, 57.5” impeller.
- 35,000 gpm (2,200 l/s) @ 350 rpm.
- 6.5” (165 mm) sphere clearance.
- 2000 kW GIW Hydraulic Lab drive train.
- Sump with bottom entry and exit to keep solids in pipeline.

Test Setup and Execution

Test Protocol

- Test duration: 4 hours.
- 1,500 lb (680 kg) of rock added at start of test and every 15 minutes.
- Total rock user per test: 24,000 lb (11,000 kg).
- Ending concentration 6% by volume (1.1 slurry SG).
- Extreme solids degradation was expected.
- Focus of test: qualitative (comparative) results.

Test Setup and Execution

Sampling Technique

- 6.5 ft (2 m) section of pipe was used to "cut a sample" of the slurry.
- Recirculating solids deposit in the pipe after a "hard stop".
- For qualitative examination only.

"pan"

> 1"

> 3"

Test Setup and Execution

Sampling Technique

- Degradation of large solids was virtually complete.
- Very few solids > 3" (75 mm) remained. (One or two per sample.)
- Less than 10% of solids remained > 1" (25 mm).

Results and Discussion

Challenges

Many challenges were encountered during testing, including:

- Occasional breaking of the test samples.
- Plugging of the impeller.
- Wear of pipe elbows.
- Making sense of the data.

Results and Discussion

Relative Wear Rates

4140 Steel

High Strength White Iron

High Chrome White Iron

80% Tungsten Carbide Insert

Key learnings

- Hardness dominated in most cases over strength.
- Some tungsten carbide grades experienced spalling, however …
- … properly supported tungsten carbide inserts of certain grades showed outstanding performance.

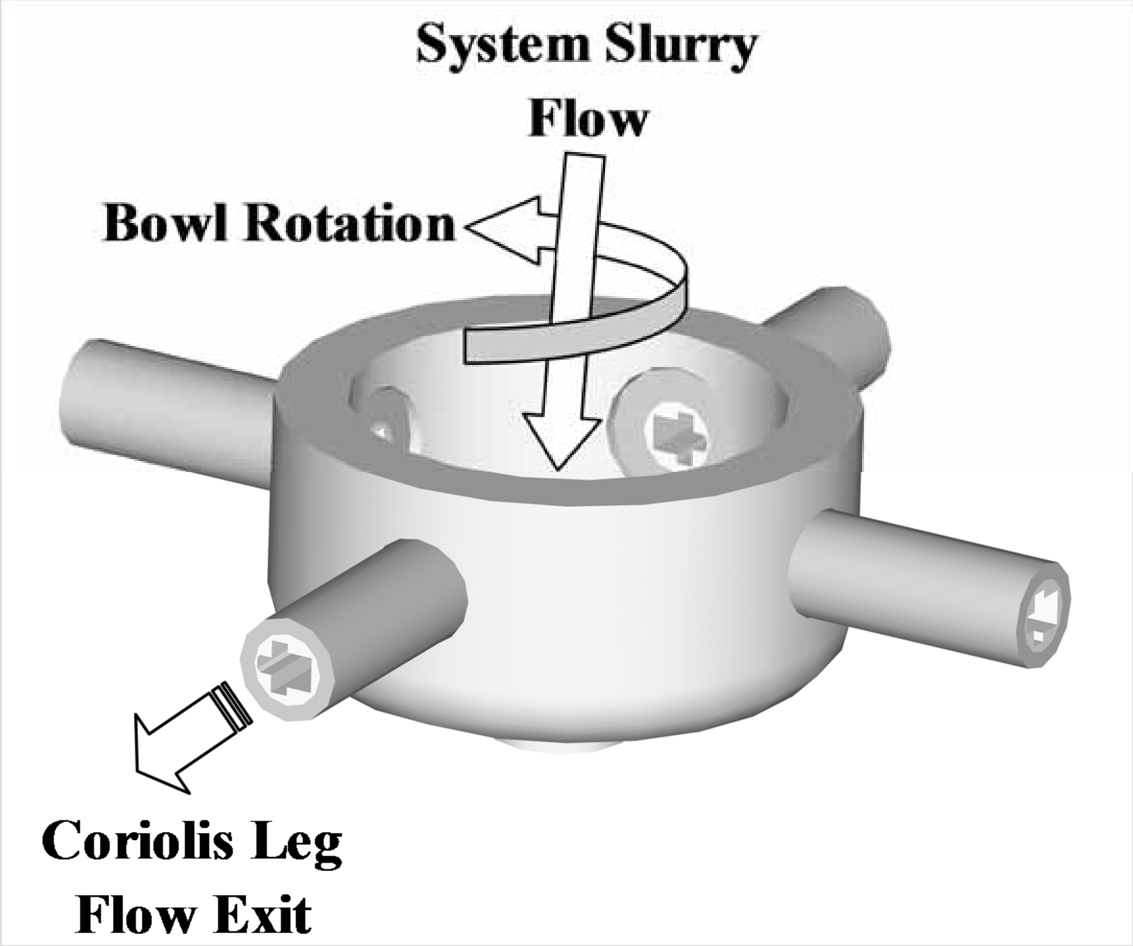
Material	Relative impact wear resistance	Comments
4140 Steel	0.21	
WD29G White Iron	0.72	Ave. hardness 495 HBN
High Chrome White Iron	1.00	Baseline. Ave. hardness 627 HBN
88% Tungsten Carbide	1.11	Most volume loss due to chipping. Tested at 10 m/s only.
Chrome-Moly White Iron	1.17	Ave. hardness 654 HBN
Endurasite White Iron	1.25	Ave. hardness 677 HBN
Hypereutectic White Iron	1.42	Tested at 9.1 m/s only. Ave. hardness 729 HBN
Tungsten Carbide Cladding	1.65	Tested at 7.6 m/s only
80% Tungsten Carbide	5.29	No large scale chipping seen up to 10 m/s.

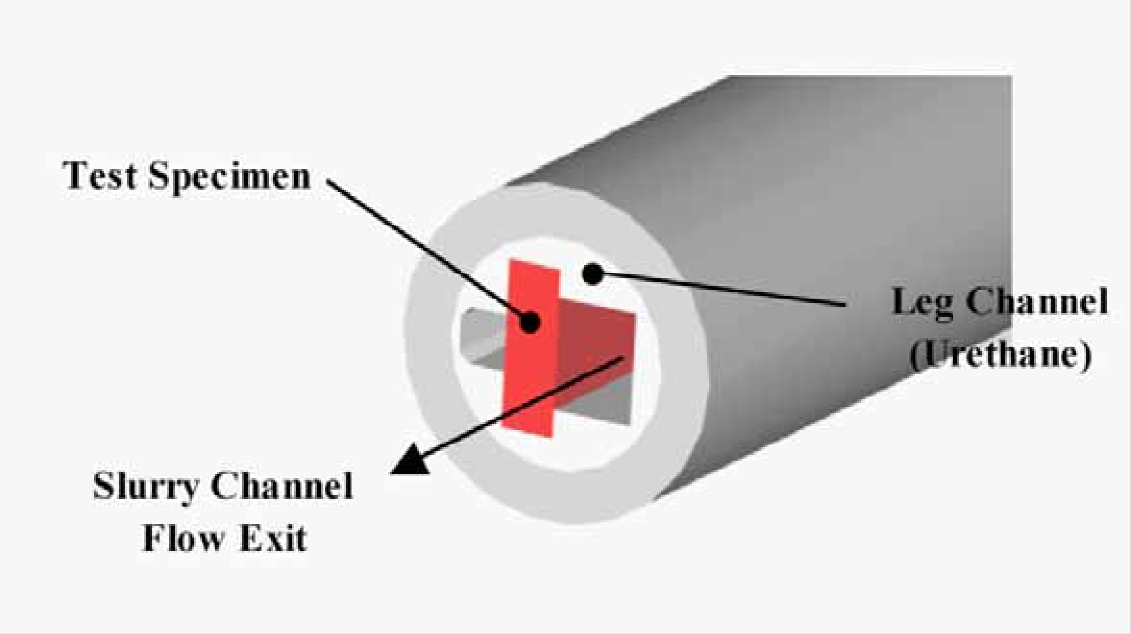
Table 2. Summary of relative impact wear resistance against large solids

Results and Discussion

Relative Wear Rates

- Baseline = 1.0 for HCWI.
- Based on volumetric loss.
- Pre-test hypothesis: stronger materials might do better than hard materials under severe impact wear.
- Actual result: Harder wear materials did better in most cases.





$$E_{SP} = (\rho_S - \rho_L)\, \omega^2\, r\, C_O\, (Q/h) / W$$

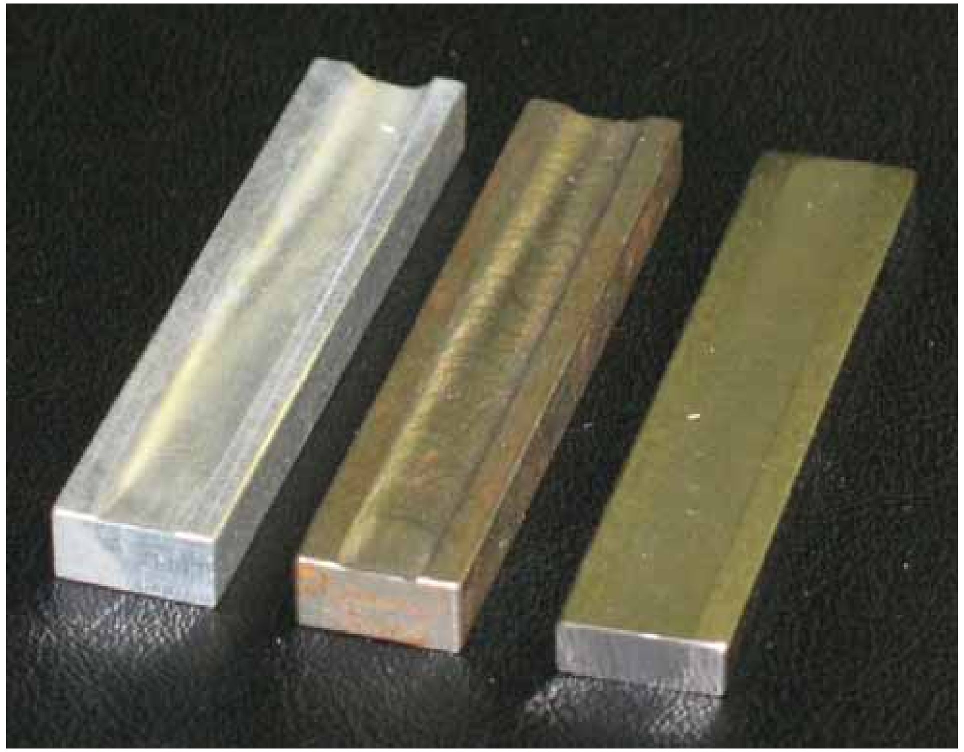
where:

E_{SP}	= specific energy
$(\rho_S - \rho_L)$	= solids – liquid density
ω	= rotational velocity
r	= radius of wear
C_O	= volumetric concentr.
(Q/h)	= channel flow / height
W	= wear rate

Results and Discussion

Comparison with Sliding Wear

- Based on previously executed “Coriolis” type sliding wear tests.



Material	Relative impact wear resistance	Relative sliding wear resistance in Coriolis wear test with 600 micron sand.
4140 Steel	0.21	0.05
WD29G White Iron	0.72	0.75
High Chrome White Iron	1.00	1.00
88% Tungsten Carbide	1.11	na
Chrome-Moly White Iron	1.17	1.25
Endurasite White Iron	1.25	1.5
Hypereutectic White Iron	1.42	0.95
Tungsten Carbide Cladding	1.65	6.10
80% Tungsten Carbide	5.29	2.15

Table 3. Comparison of relative rock impact vs. sand sliding wear resistance.

Comparison with Sliding wear

- In some cases, harder and more brittle materials did better in sliding than impact, relative to the baseline High Chrome White Iron.
- With other materials, the comparison is less clear.
- More study is needed to validate and explain these trends.

Results and Discussion

Velocity Dependence

- Typical velocity dependence for impact wear is to the third power.
- Based on the physics of impact energy transfer.

$$W_I = C * E * N$$

Where:

W_I = Impact wear rate (volumetric loss / unit time).

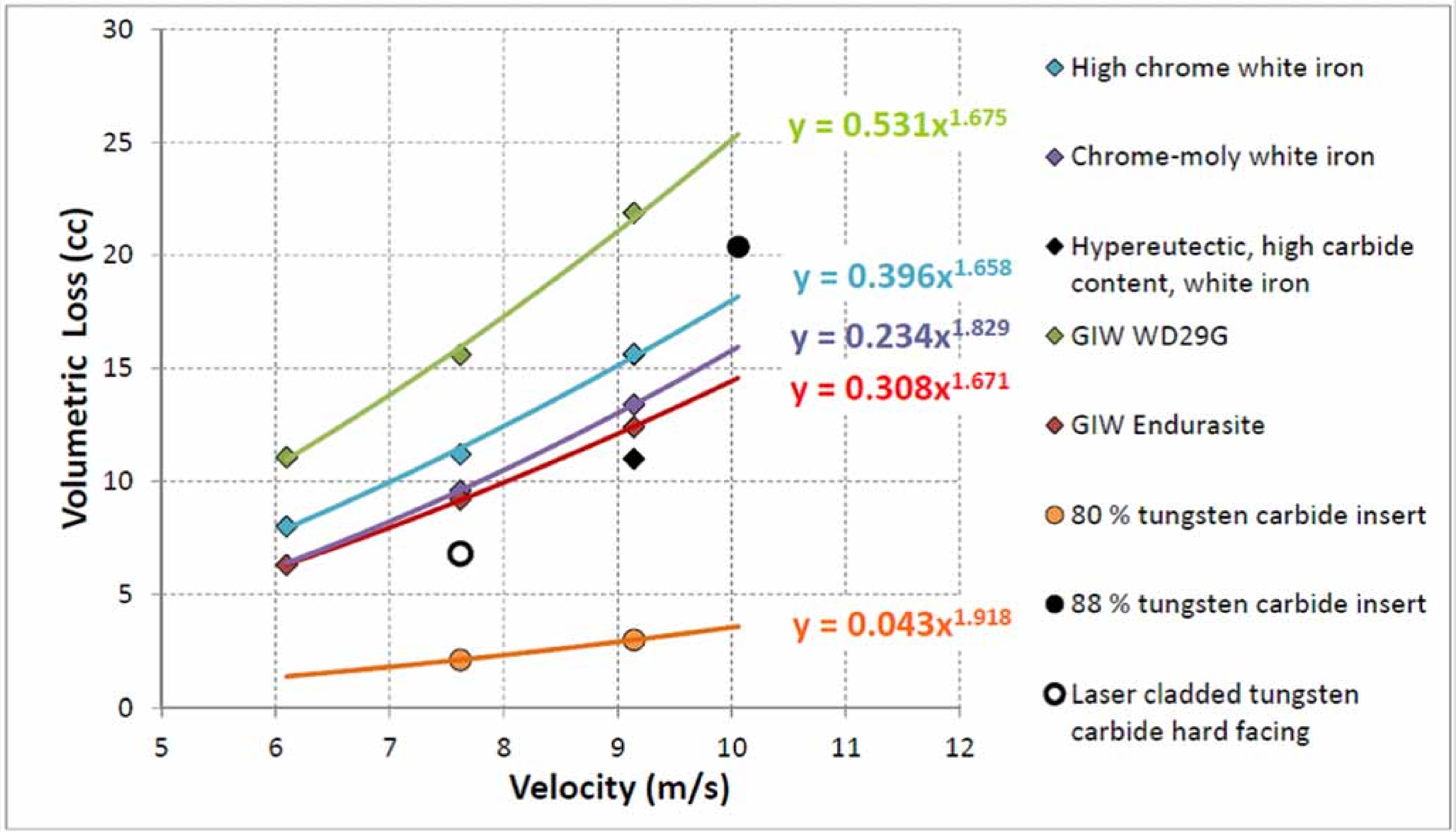
C = Wear coefficient (volumetric loss / unit energy), a property of the material.

E = Impact energy (energy / particle impact), proportional to particle velocity^2

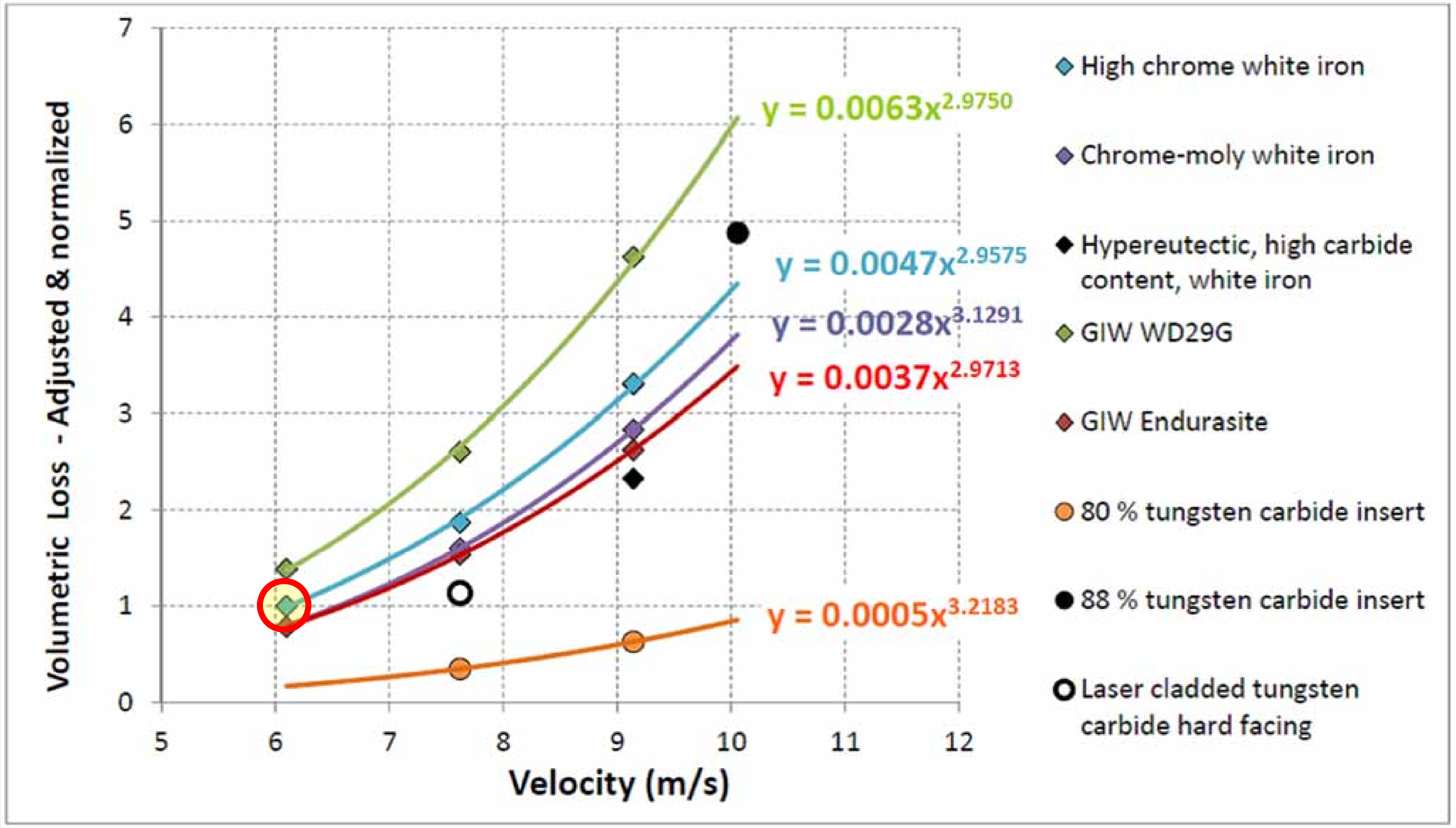
N = Number of impacts (particle impacts / unit time), proportional to particle velocity, assuming constant concentration.

Results and Discussion

Velocity Dependence



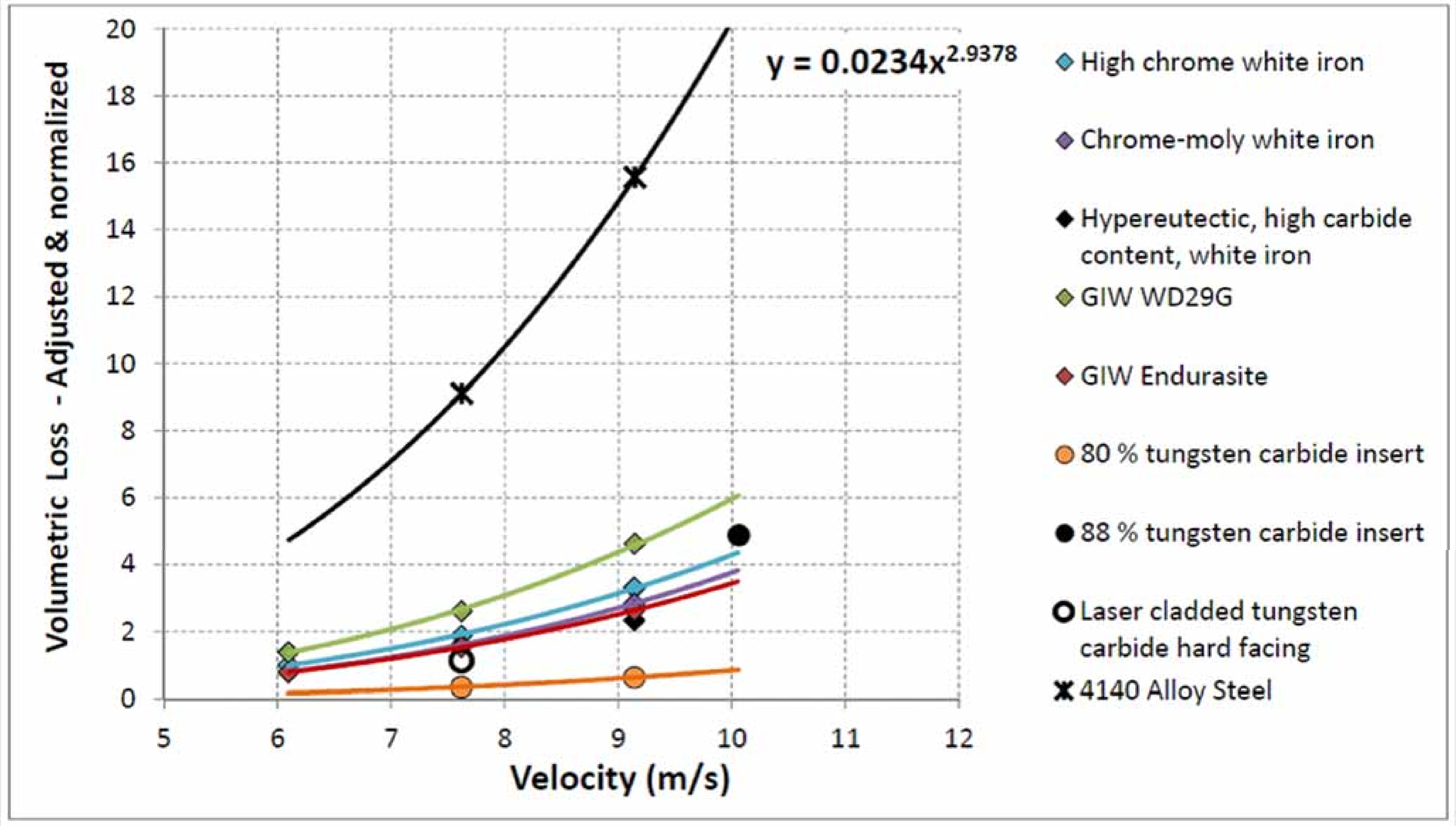
- Observed velocity exponent of 1.7 (average) was much less than 3, however …
- … complete degradation of the large solids effectively eliminated number of impacts as a variable.
- In other words, the number of impacts (N) was about the same for each test, regardless of velocity, since the number of particles was fixed.
- Correcting for this increases the observed exponent to 2.7.



Results and Discussion

Velocity Dependence

- In fact, higher velocity tests will actually produce fewer impacts per test, since the impact force is greater and degradation will occur more quickly.
- If this correction is assumed to be equivalent to an exponent of 0.3 (arbitrary) the expected third power exponent is achieved.
- NOTE: Results shown here have been normalized to HCWI at lowest velocity.



Results and Discussion

Velocity Dependence

- The above analysis is validated (in a qualitative way) by the result of the 4140 alloy steel, which should follow the third power dependence on velocity, being a standard ductile material with no specialized or brittle properties.

Impeller Wear Prediction

The Model

$$W_{VL} = \frac{1}{\left(C_{VL} \times \left(\frac{TPH_{ref}}{TPH_a}\right) \times \left(\frac{V_{Iref}}{V_{Ia}}\right)^{ExpV} \times W_{rel}\right)}$$

Where:

W_{VL} = Impact wear rate (impeller vane loss / unit time)

C_{VL} = Vane wear coefficient (hours / unit vane length) for reference slurry, tonnage and impact velocity.

TPH_{ref} = Reference solids transport rate (tonnes per hour)

TPH_a = Actual solids transport rate in the system to be modeled

V_{Iref} = Reference vane impact velocity (meters / second)

V_{Ia} = Actual vane impact velocity (meters / second)

ExpV = Exponent of impact velocity

W_{rel} = Relative material impact wear resistance compared to high chrome white iron (Ref Table 2)

- Used to predict impact wear along the length of the vane.
- Requires a reference wear rate (calibration coefficient) for a similar slurry at a particular velocity.
- Linear correction for tonnage.
- Calibrations from impact wear experiments:
  - o Velocity exponent, *ExpV*
  - o Material resistance, W_{rel}

$$W_{VL} = \frac{1}{\left(C_{VL} \times \left(\frac{TPH_{ref}}{TPH_a}\right) \times \left(\frac{V_{Iref}}{V_{Ia}}\right)^{ExpV} \times W_{rel}\right)}$$

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ExpV = Exponent of impact velocity

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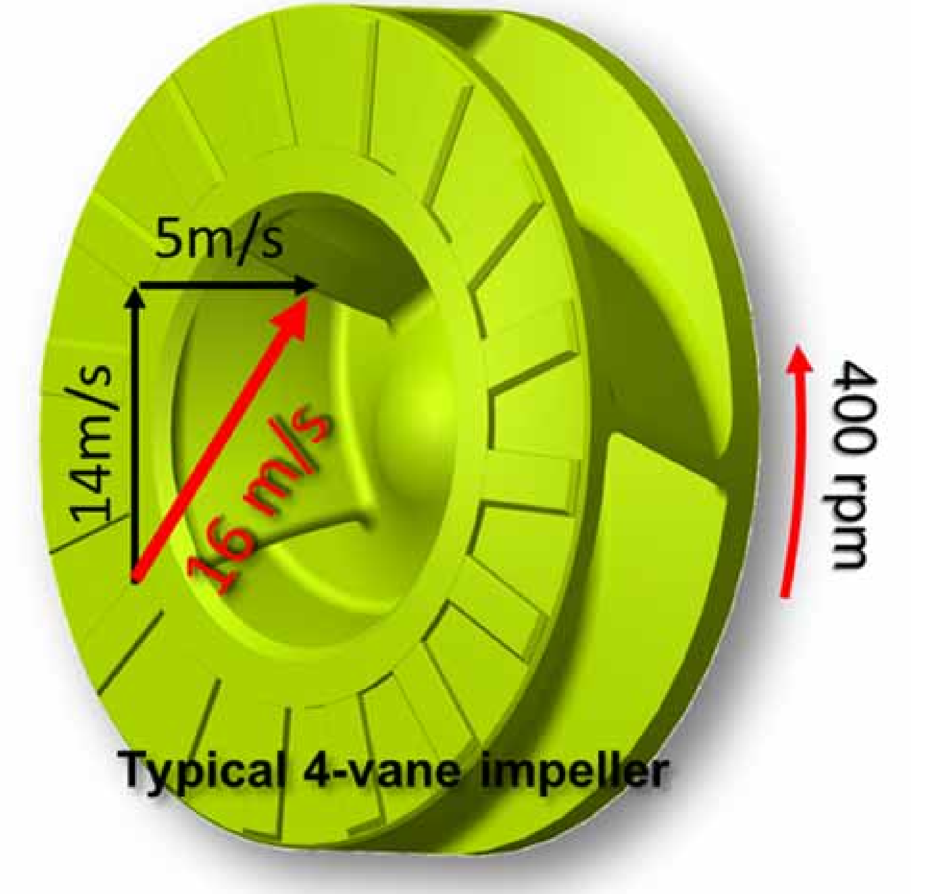
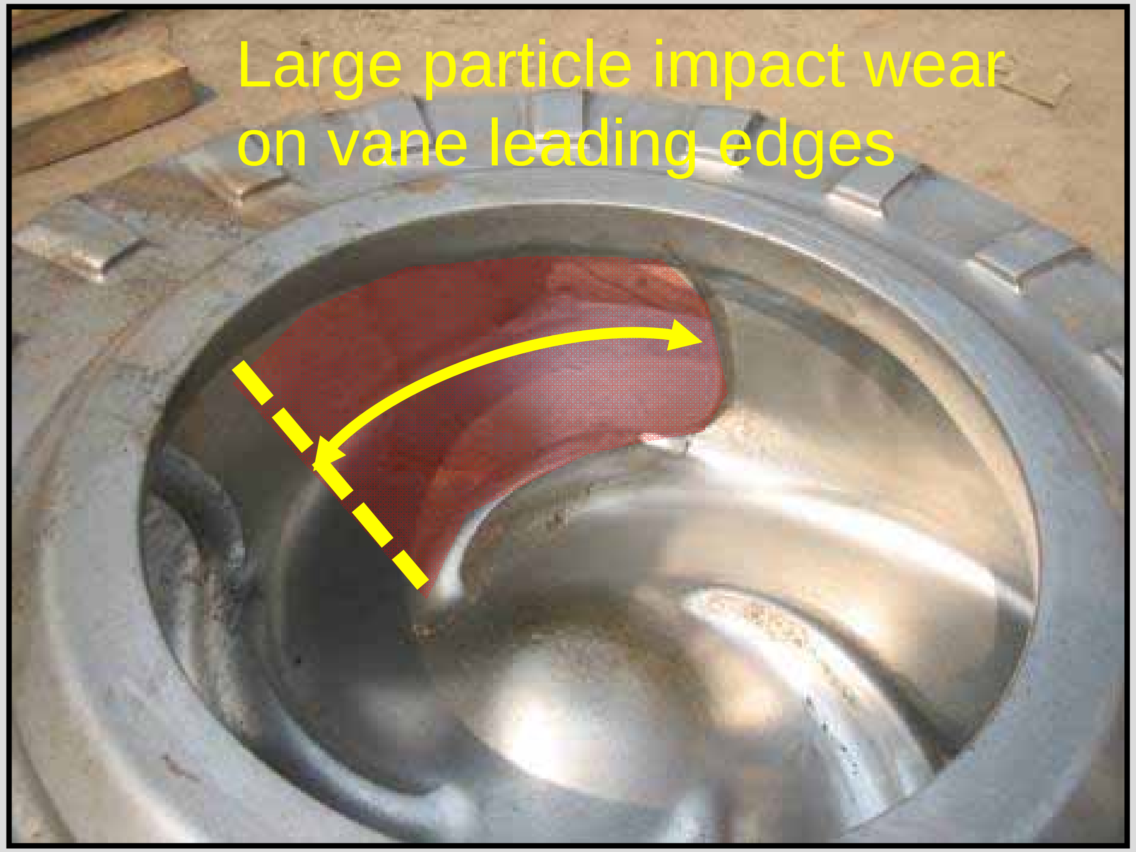
Impeller Wear Prediction

The Model

Actual impact velocity **V_I** is the vector sum of the inlet flow velocity and vane leading edge speed



New Impeller



Almost new

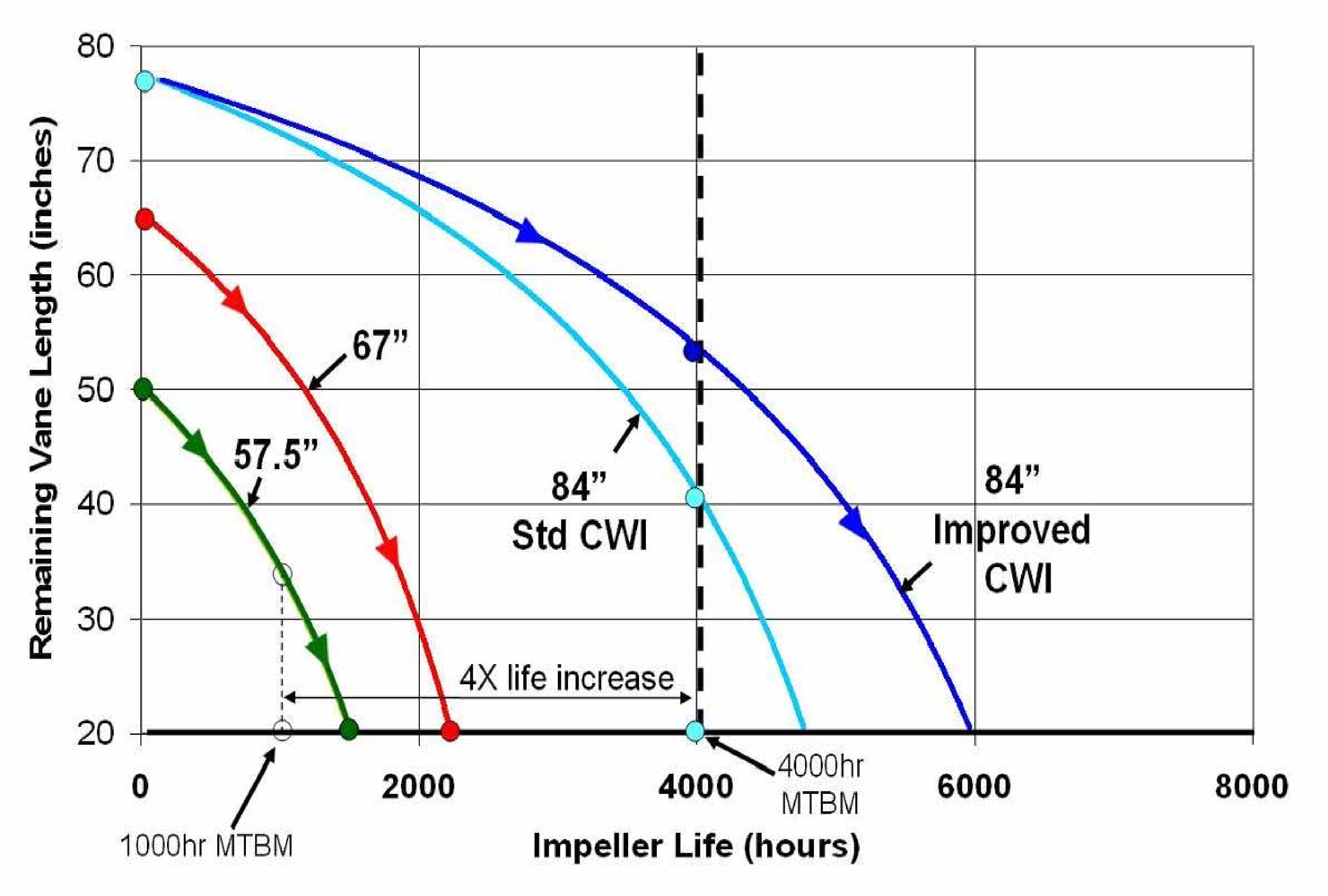
(< 2000 hrs)

Impeller Wear Prediction

The Application

First application of model in Oil Sands hydrotransport.

- Large solids, up to 5” (125mm).
- Steady conditions and good data collection.
- Short life allowed for quick results.
- High cost of downtime helped drive funding of project (c.a. $100,000 / hr).



Impeller Wear Prediction

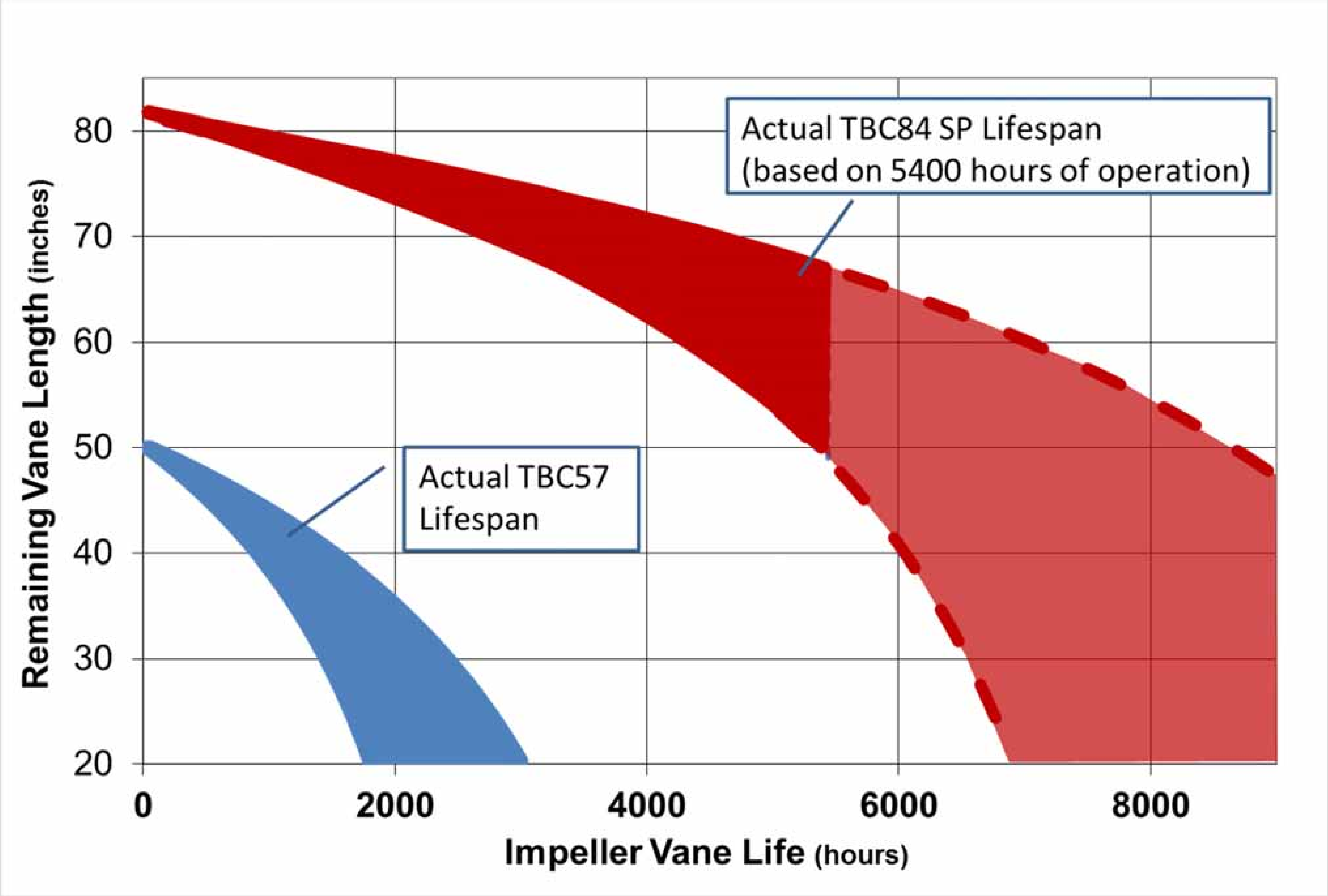
Calculated results

- 57.5” pump used to determine calibration coefficient C_{VL}
- Result validated by known results with a 67” impeller.
- Model then used to predict performance of new 84” design for a target 6000 operating life.
- All with same inlet diameter.
- Key result: A large impeller at the same head and suction diameter could achieve a significant increase in wear life.

Impeller Wear Prediction

Calculated results

- Head is proportional to the circumferential velocity at the vane outlet.
- Therefore, impeller rotational speed decreases as the vane outlet diameter increases.
- If the inlet diameter remains constant, reduced rotational speed means reduced inlet edge impact velocities.
- The larger diameter also allows a longer vane, further increasing wear life.



Impeller Wear Prediction

Field Performance

- 84” pump rebuilt at 5400 hours due to required maintenance outage for other equipment.
- Based on remaining vane length, minimum life of 6500 hours would have been met.
- Velocity dependence exponent of 2.85 best fits the actual field data.

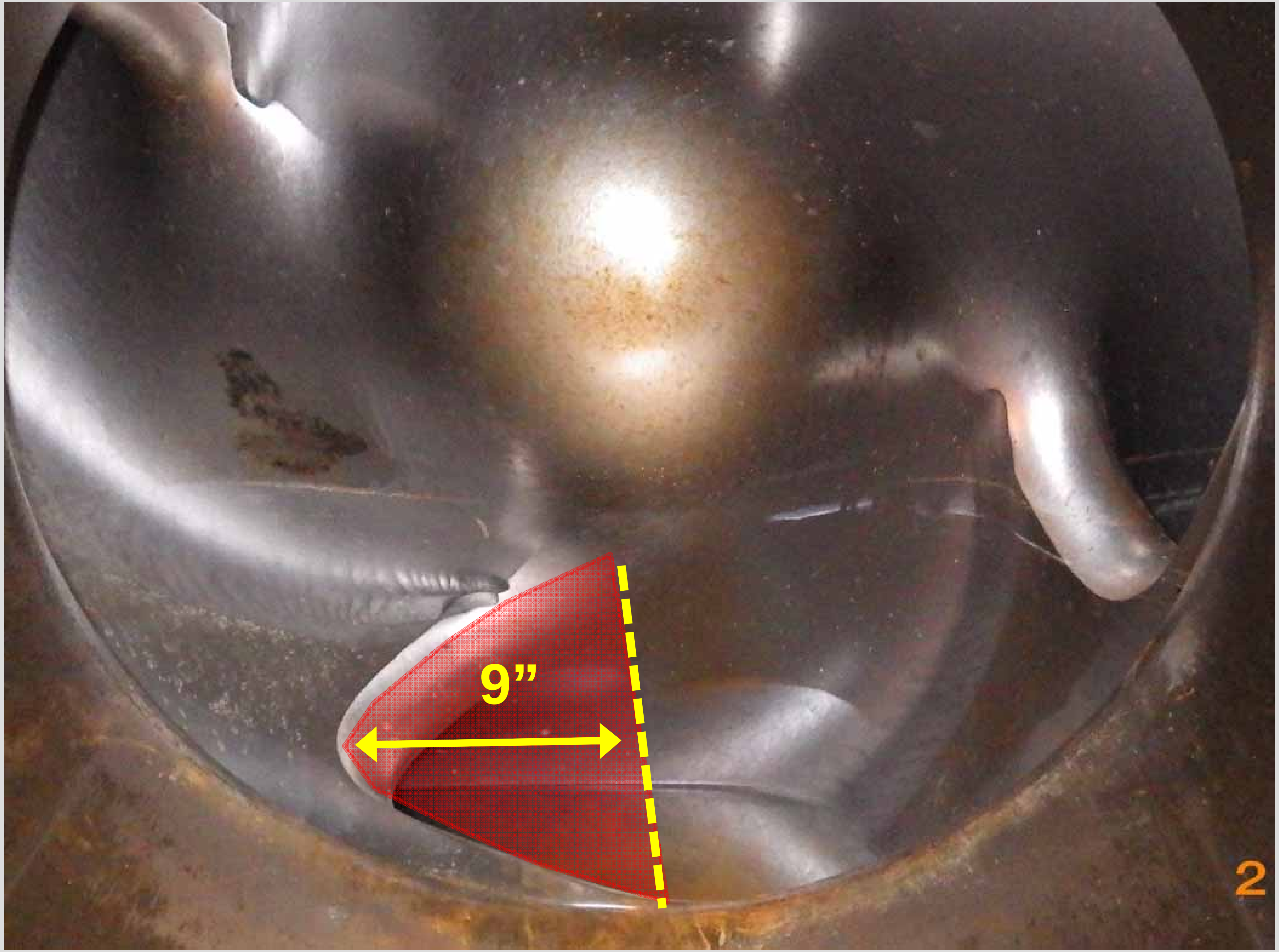
Impeller Wear Prediction

Field Performance

57.5” impeller @ 1900 hours

27” wear, 23” remaining

2000 hour expected life span



Impeller Wear Prediction

Field Performance

84” impeller @ 2950 hours

9” wear, 72” remaining

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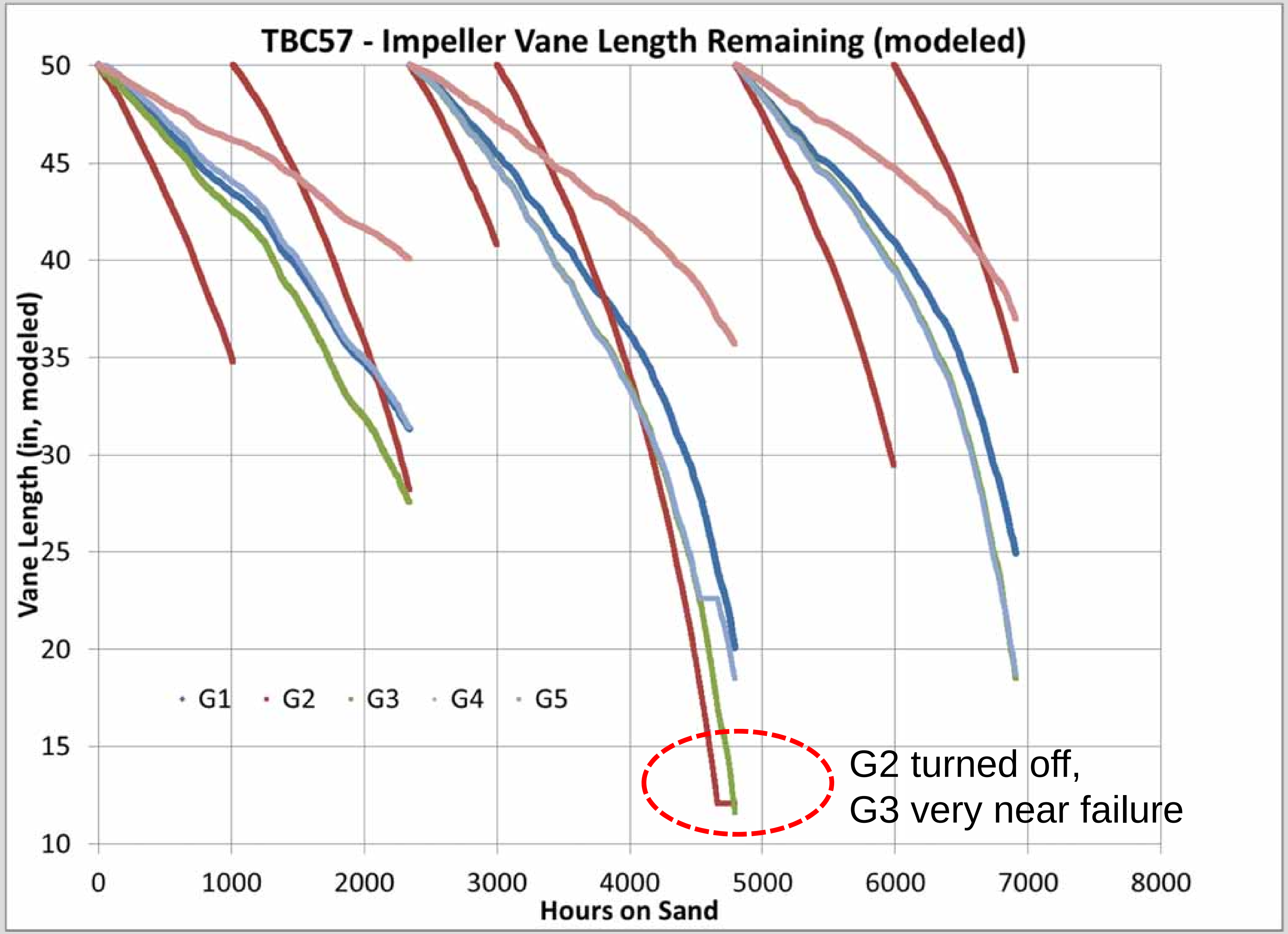
Impeller Wear Prediction

Field Performance

84” impeller @ 5400 hours

26-33” wear, 49-56” remaining

> 6500 hour expected life span



Impeller Wear Prediction

Real-time Monitoring

Once the wear model has been calibrated to a given application, the model can be used to continuously predict wear, based on actual pump operation.

Real-time wear prediction can be useful in predicting time to failure, even if operating conditions change from those for which the model was calibrated.

Multiple pumps in series can be rebalanced with speed offsets, or even turned off and free-wheeled, in response to remaining vane length predictions.

Summary and Conclusions

- Slurry pump wear materials under heavy impact loading differed from their typical sliding wear performance, although many similar trends were observed.
- In particular, wear performance correlated to hardness in many cases, although the degree of correlation was different.
- The exponent of velocity dependence on wear was found to be in the range of 2.7 to 3.0, which is similar to the expected theoretical result of 3.0 for impact wear in general.

Summary and Conclusions

- An impeller vane wear model was developed based on an incremental calculation of wear as a function of impact velocity over time.
- The model was validated by field results in oil sands hydrotransport, where rock and lump top size reaches 5”.
- The back calculated velocity dependence seen when using this model to evaluate field results was on average 2.85.
- Large increases in the pump maintenance interval can be achieved in cases where vane impact wear dominates by converting to a larger, slower runner pump of the same inlet size.