ASSESSING THE RESPONSE OF TUMBLING MILLS TO THE REPLACEMENT OF BALLS BY RELO GRINDING MEDIA (RGM)

PART 1. COMPARATIVE BENCH-SCALE EXPERIMENTS AND DEMONSTRATION FULL-SCALE TEST

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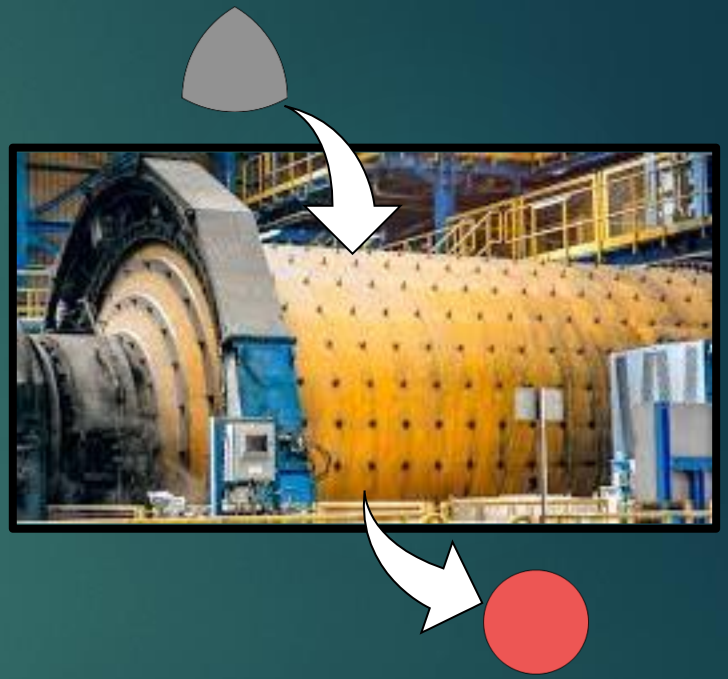
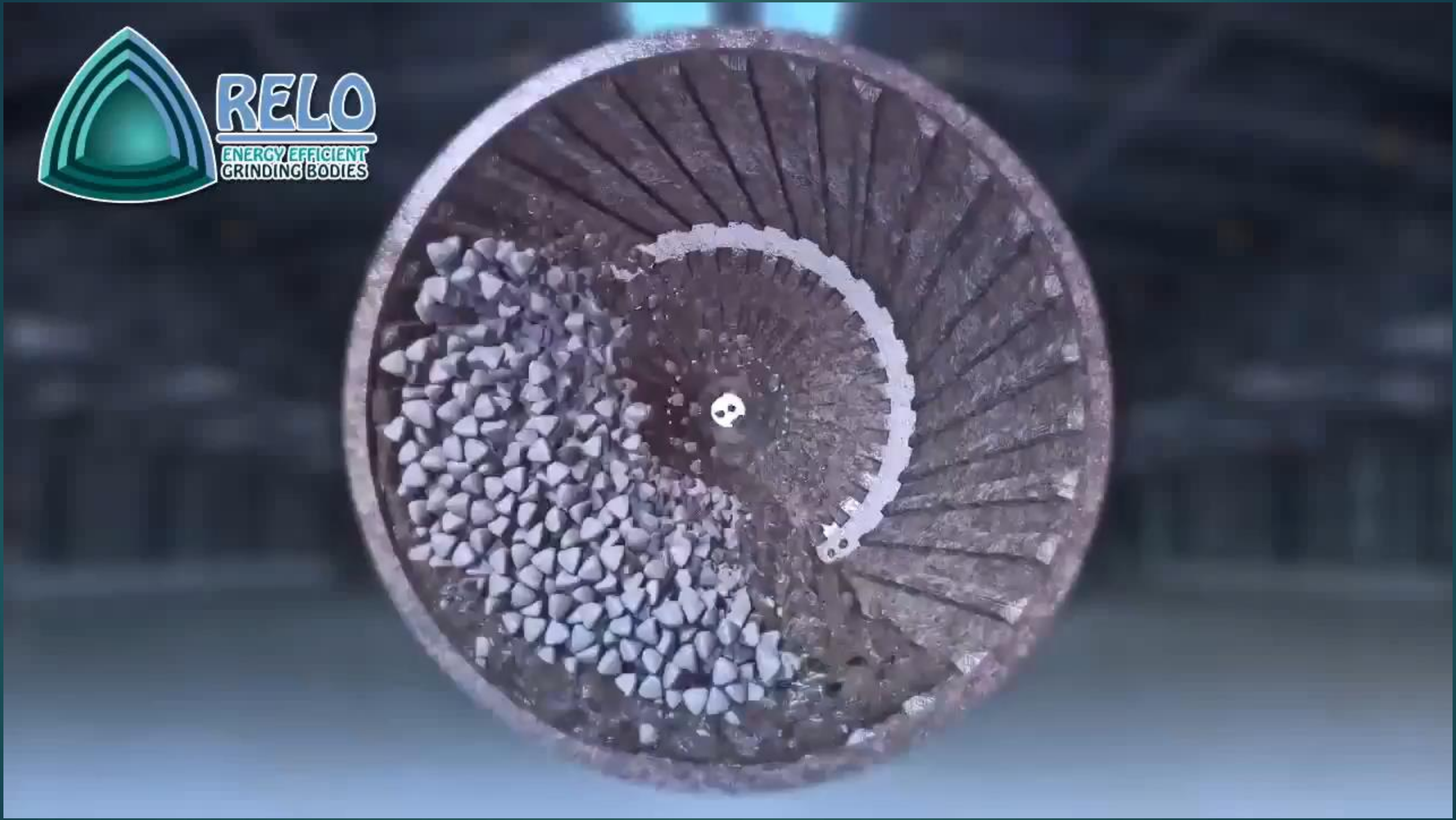
The Relo Grinding Media (RGM)

- Innovative grinding media
- Shaped like Reuleaux tetrahedra
- Designed to replace spherical grinding media (balls) in tumbling mills
- Made of steel (all types commonly used for making balls)





Developed by Evlogi Vatzev

Takeaways

- The RGM are a intriguing technology
  - They have a significantly higher packing density than a ball charge which increases the effect of filling ratio on power draw.
  - They are subject to greater centrifugal forces than balls in tumbling mills (which affect their trajectories within the mill).
- A new scale-up procedure needs to be developed for taking into account the unique behaviour of RGM in tumbling mills.
- Results of an industrial-scale test indicated that replacing balls by RGM in a tumbling mill led to an 89% increase of capacity.
- Upcoming large-scale RGM tests will demonstrate the reproducibility of the preliminary industrial test results.

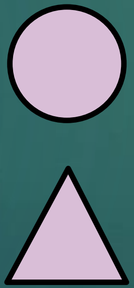
Alternative Shapes

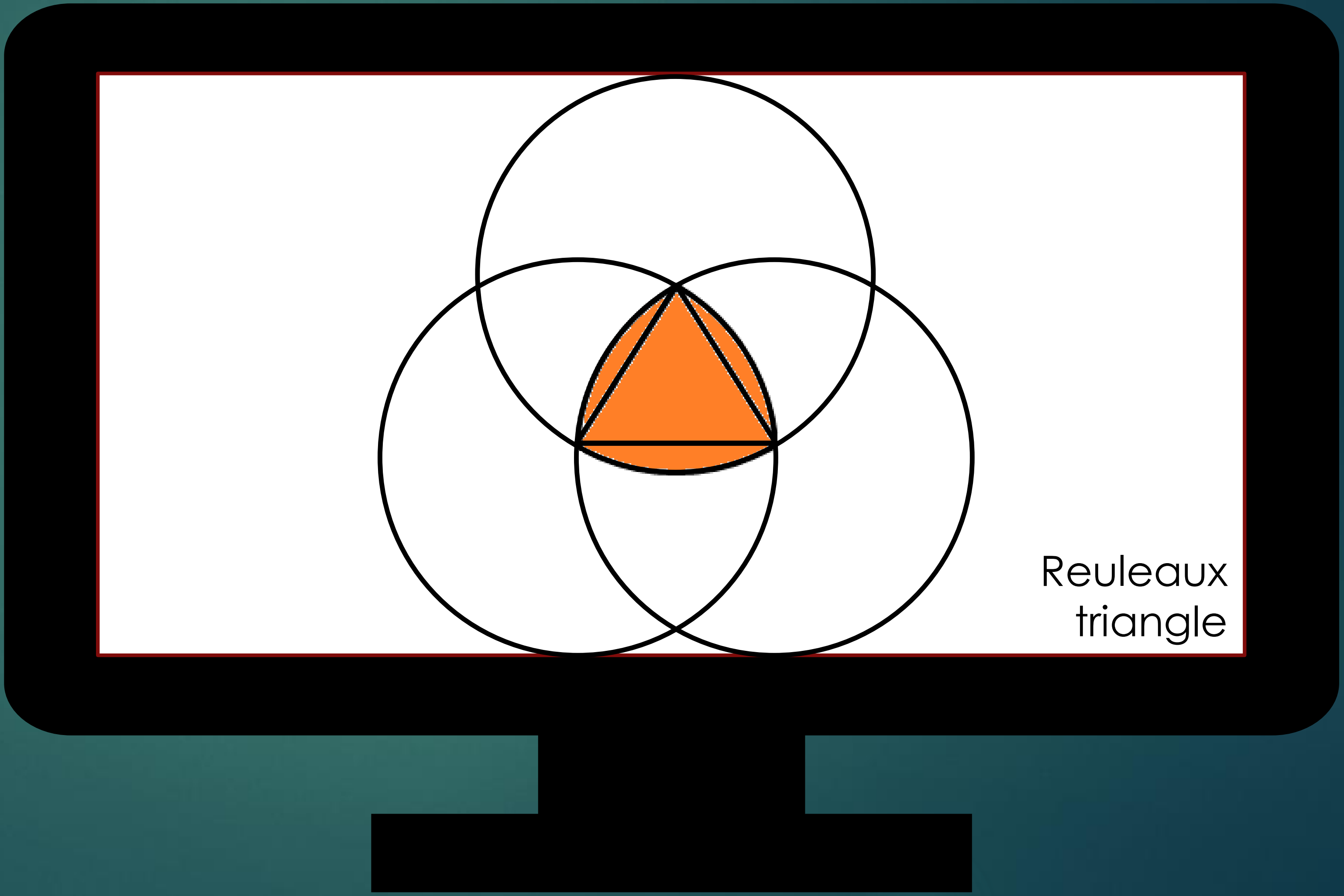
- Ball milling is a very inefficient process
- Different shapes have been tested by others. In most cases, grinding efficiency improvements (over balls) were reported.
- However, for different reasons (cost, wear, availability), none of them has been sustainably adopted by the industry
- The RGM has a high degree of symmetricity (providing resistance of wear) and can be fabricated in different sizes, by casting, within existing facilities.

Reuleaux Geometry

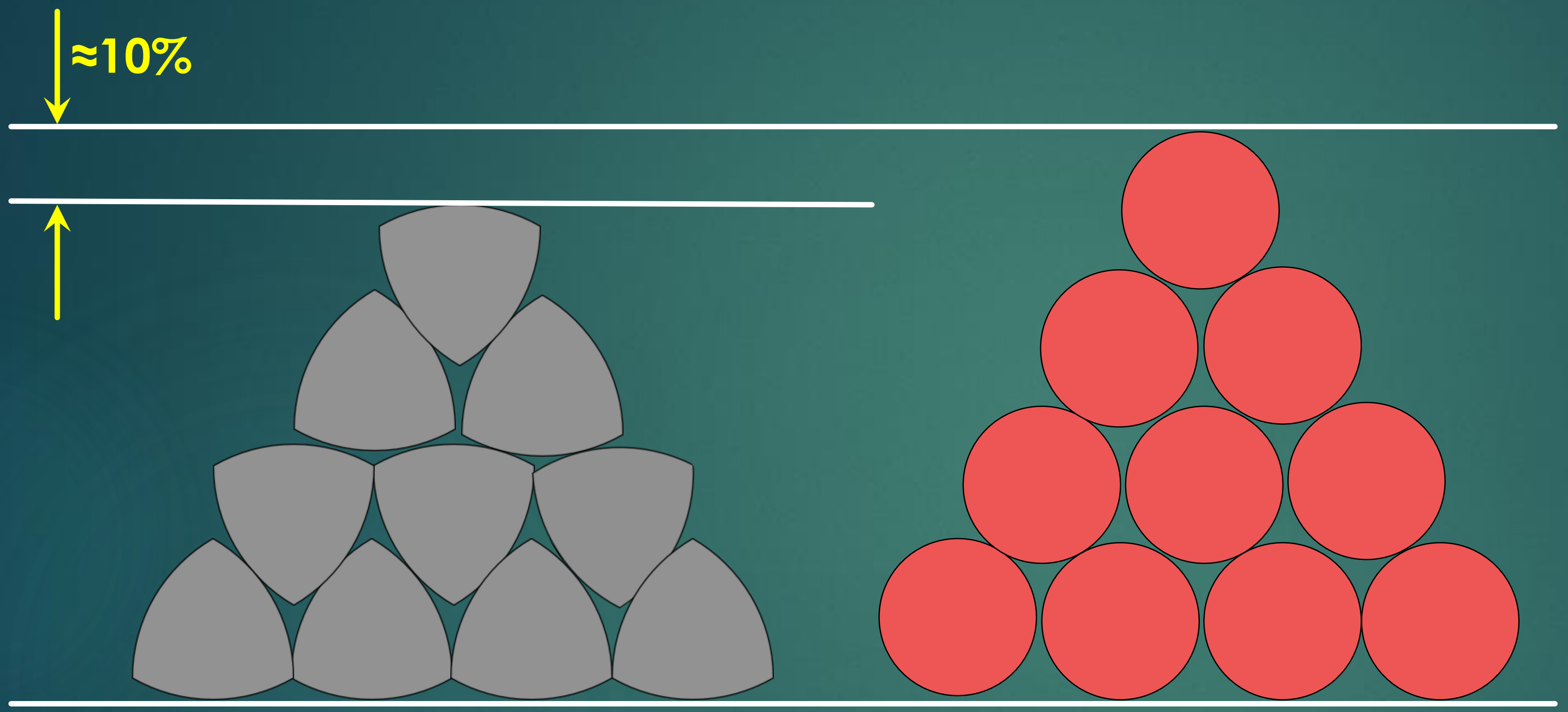
Smaller intersecting circles

Larger intersecting circles



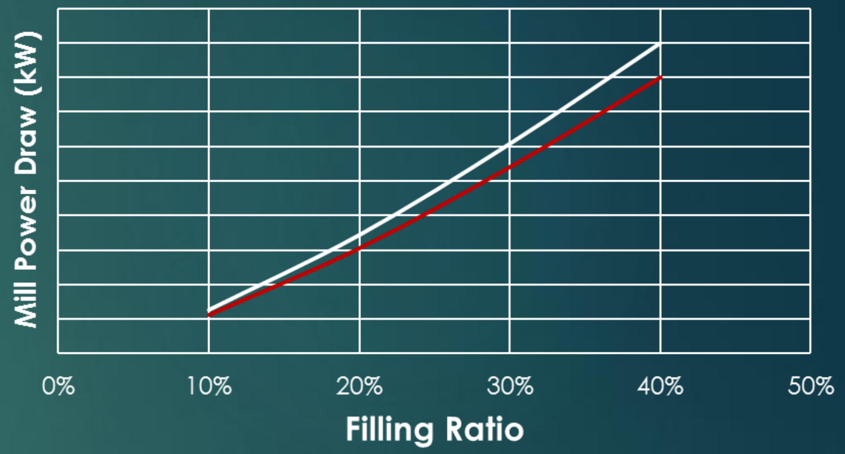


Packing and Filling Ratio



The larger the intersecting spheres, the higher the packing

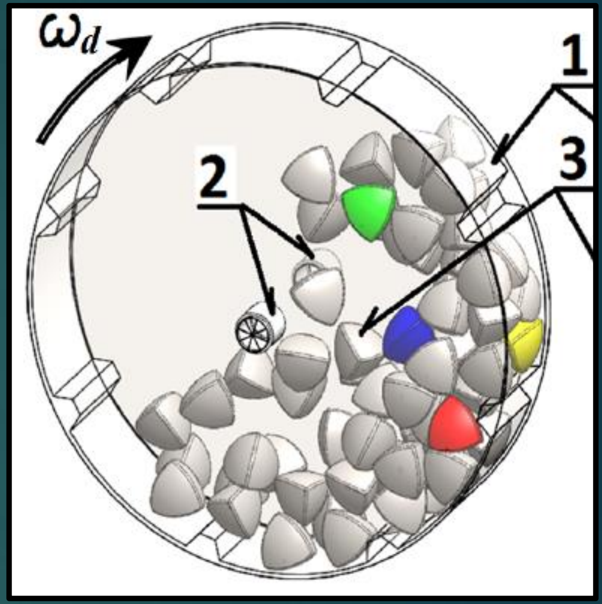
Worst packing of all convex shapes

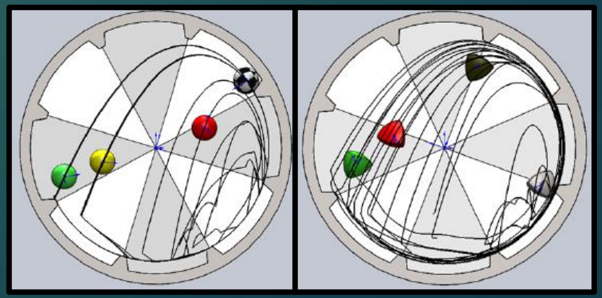


Centrifugal Forces

- Damyanov et al. compared the behaviour of Reuleaux tetrahedra in tumbling mills against balls using 3D-CAE simulations.
- The "ball size to mill diameter" ratio (120/1200 mm) was large and the number of simulated grinding media was low (62) but interesting conclusions can still be drawn from the simulations
  - The RGM are subject to greater centrifugal forces (shorter distance between centre of gravity and surface)

  - Consequently, RGM would be projected (travelling longer distances) more often, and be cascaded less frequently, than balls.





Bench-Scale Testing

- Applying Bond's locked-cycle test methodology
  - Dry grinding in a Bond-type bench-scale mill
  - Using equivalent masses and size distributions of RGM and balls
- Many comparative tests have been conducted with different ores. A greater gpr is always obtained when RGM are used.
- From the few large-scale results available, the Bond scale-up equation (which was developed for balls) would <u>largely over-estimate</u> the Work Index (W_i) when RGM are used.

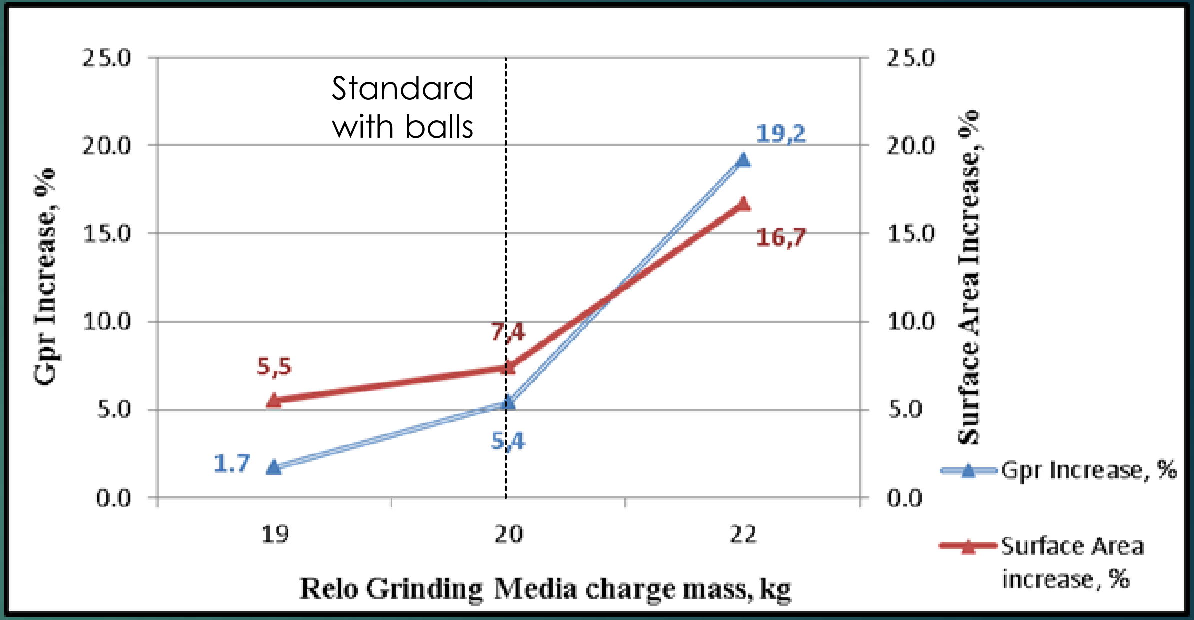
$$W_i = \frac{44.5}{P_{100}^{0.23} \times gpr^{0.82}\left[\left(\frac{10}{\sqrt{P_{80}}}\right) - \left(\frac{10}{\sqrt{F_{80}}}\right)\right]}$$

With RGM

Bench-Scale Testing

Effect of Surface Area

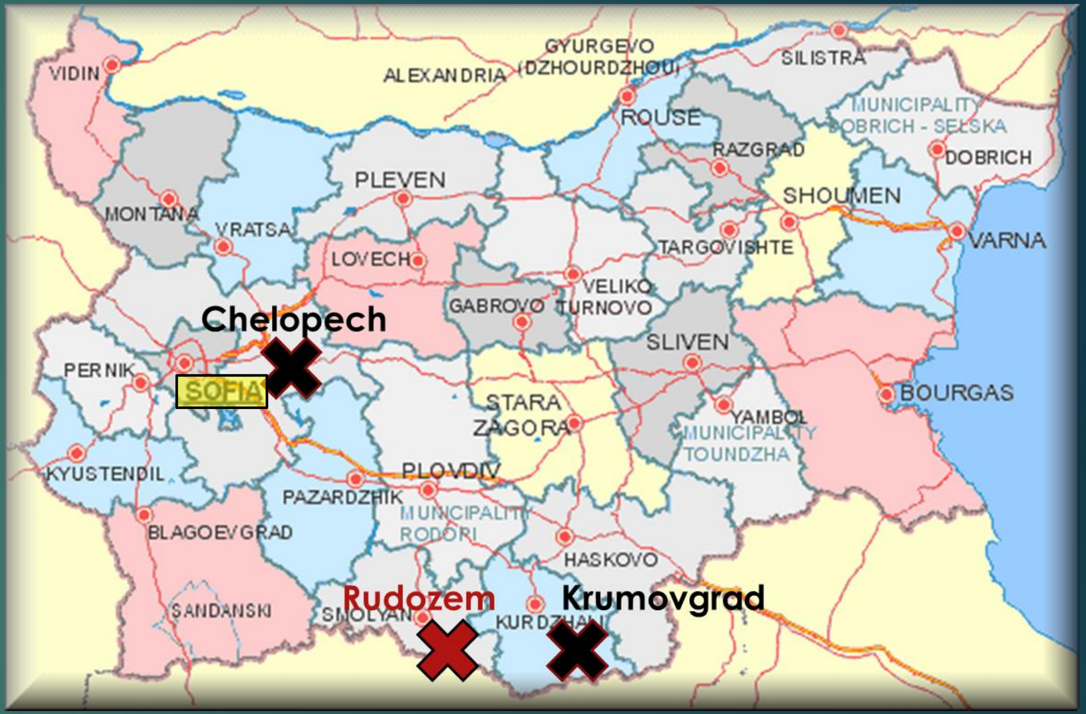
- At equivalent volume, an RGM has a significantly larger (9.4%) surface area than a sphere.
- Reverse Bond methodology (fixed number of revolutions) was applied to measure the effect of the surface area on grinding efficiency.
- When a 20-kg mass of RGM was used, a 5.4% greater *gpr* was obtained.
- When a 22.2-kg mass of RGM was used (matching the filling ratio of balls), a 19.2% greater *gpr* was obtained



Large-Scale Testing

Set-Up

- Conducted at the Rudmetal Pb/Zn concentrator (near Rudozem, Bulgaria) from November 2016 to March 2017.
- To date, the one and only documented full-scale RGM tests
- Two parallel ball mill (75-kW) circuits, each closed with a spiral classifier.
- Eleven (11) tonnes of 60-mm RGM were specifically made for the test.
- The ball charge (8 tonnes, 45% filling) of one of the two mills was dumped and replaced by 8 tonnes of RGM.



Large-Scale Testing
Running

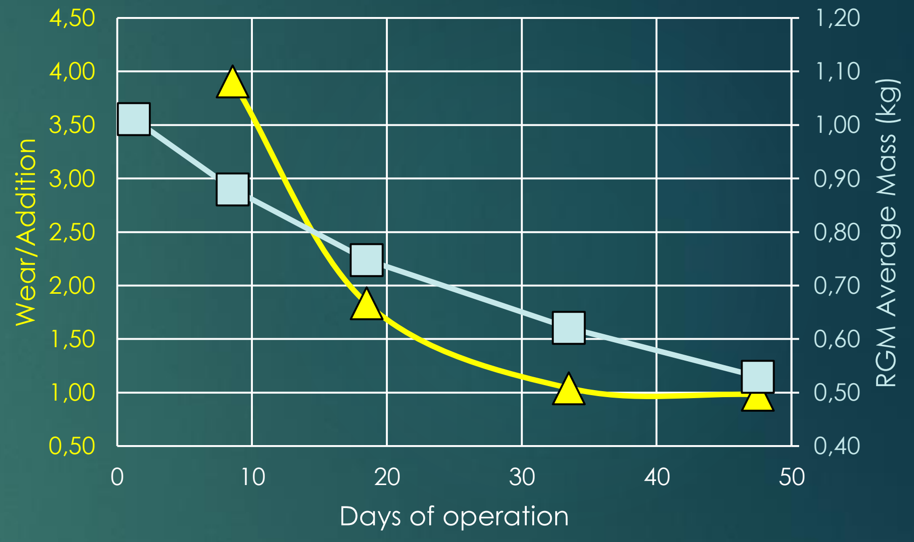
- Both circuits are used for primary grinding (coarse feed, F_{100} = 25 mm)
- In spite of a lower filling (due to higher compactness), the RGM-loaded mill motor could not initiate rotation.
- The steel charge was lowered to 7 tonnes, further reducing the mill filling ratio (down to 32%)
- The plant did not run continuously. The actual cumulative testing time was 1440 hours (equivalent to 60 days of continuous operation).

Diameter: 1.5 m
Length: 3.5 m

Large-Scale Testing

Wear

- Samples of worn RGM were taken from the mill charge throughout the test. Balances between RGM wear and addition were calculated.
- Wear and addition balanced out after 34 days.
  - RGM: (from 34 to 48 days): 0.60 kg/tonne
  - Balls (average): 1.2 kg/tonne
- After 48 days, the RGM size distribution within the charge had not fully reached equilibrium (average individual RGM mass was still dropping)
- RGM retained their shape throughout the test.

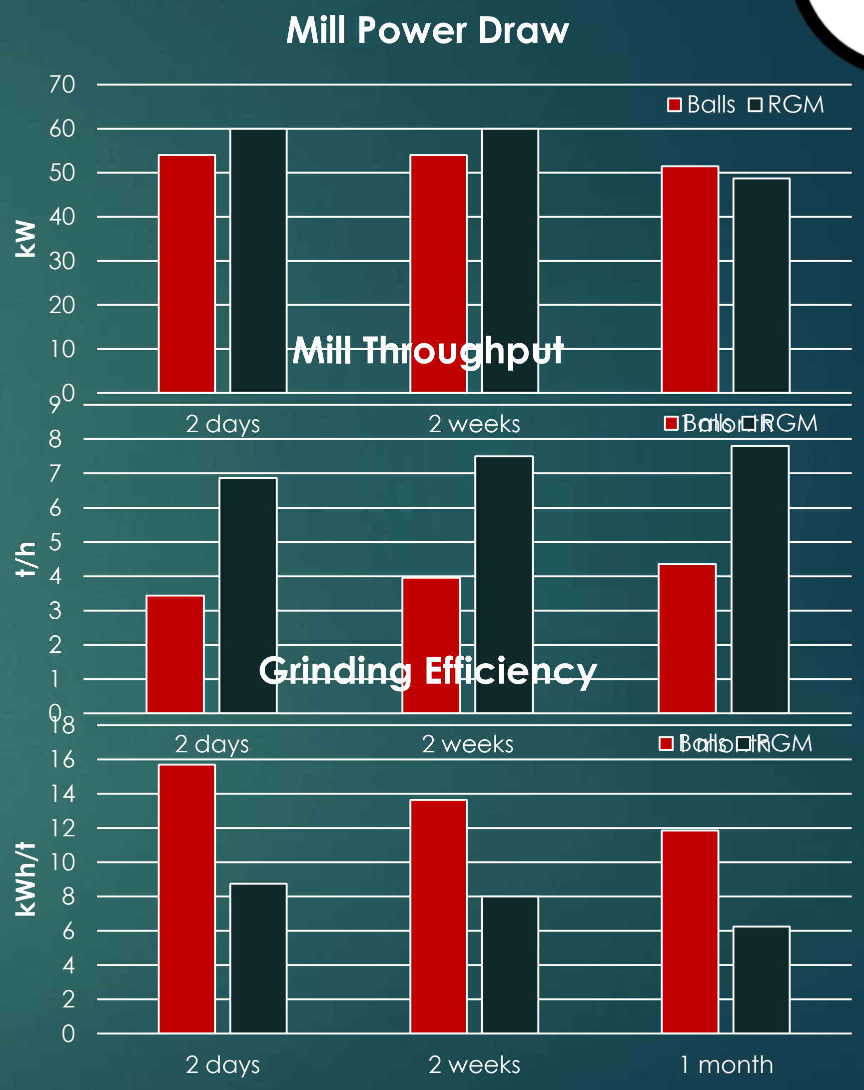


New 9 days 19 days 34 days 48 days 60 days

Large-Scale Testing

Grinding Efficiciency

- Power draw, feed tonnage and particle size of spiral classifier overflow of both circuits were monitored regularly
- The RGM-loaded mill circuit produced finer particles (higher passing 75µm)
  - Ball-loaded mill: 37%
  - RGM-loaded mill: 47%
- «Snapshots» (taken after 2 days, 2 weeks and 1 month of operation) show large difference of grinding efficiency between the two circuits.



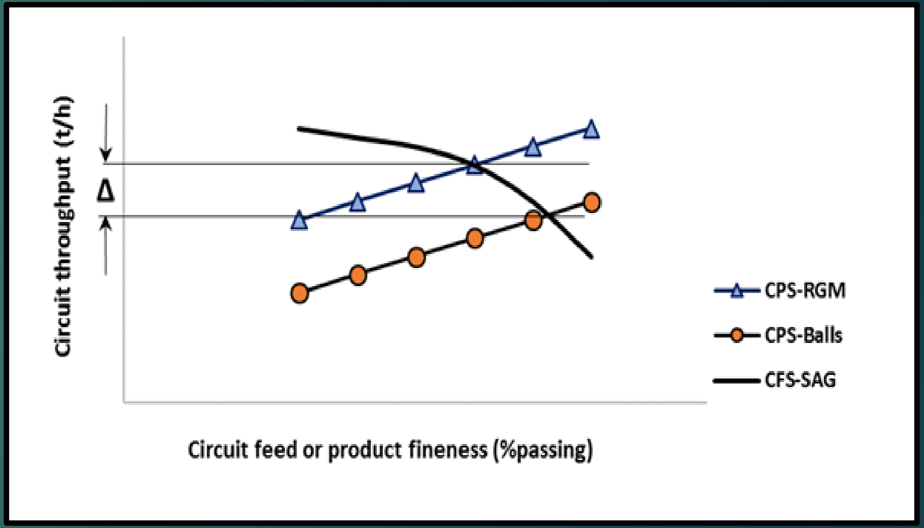
Large-Scale Testing
Discussion

- Phenomenal improvement of grinding efficiency was observed at Rudozem
- Particular case: Coarse feed, large grinding media, small tumbling mill.
- Reproducibility of results need to be demonstrated. Virtually risk-free for the test site.
- Another large-scale test will be conducted at the Erdenet concentrator (Mongolia) this year.
  - Secondary grinding application
  - Larger ball mill (900 kW)
  - Smaller grinding media (40 mm)
  - Feed circuit feed (≈100 t/h, F_{65}= 150 µm)
- Actively looking for a test site in the Americas as well.

Benefits

Different options

- Save energy (lower charge of grinding media)
- Improve fineness of grind (maintaining current throughput)
  - Often creating metal recovery improvement opportunities
- Improve grinding circuit capacity (maintaining current fineness of grind)
  - Increase transfer size between primary (SAG, HPGR) and secondary (ball mill) circuits.



Conclusions

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