Maximum in Mass Flow Rates of Hard Metal Granules Through Circular Orifices in Relation to the Angle of Repose

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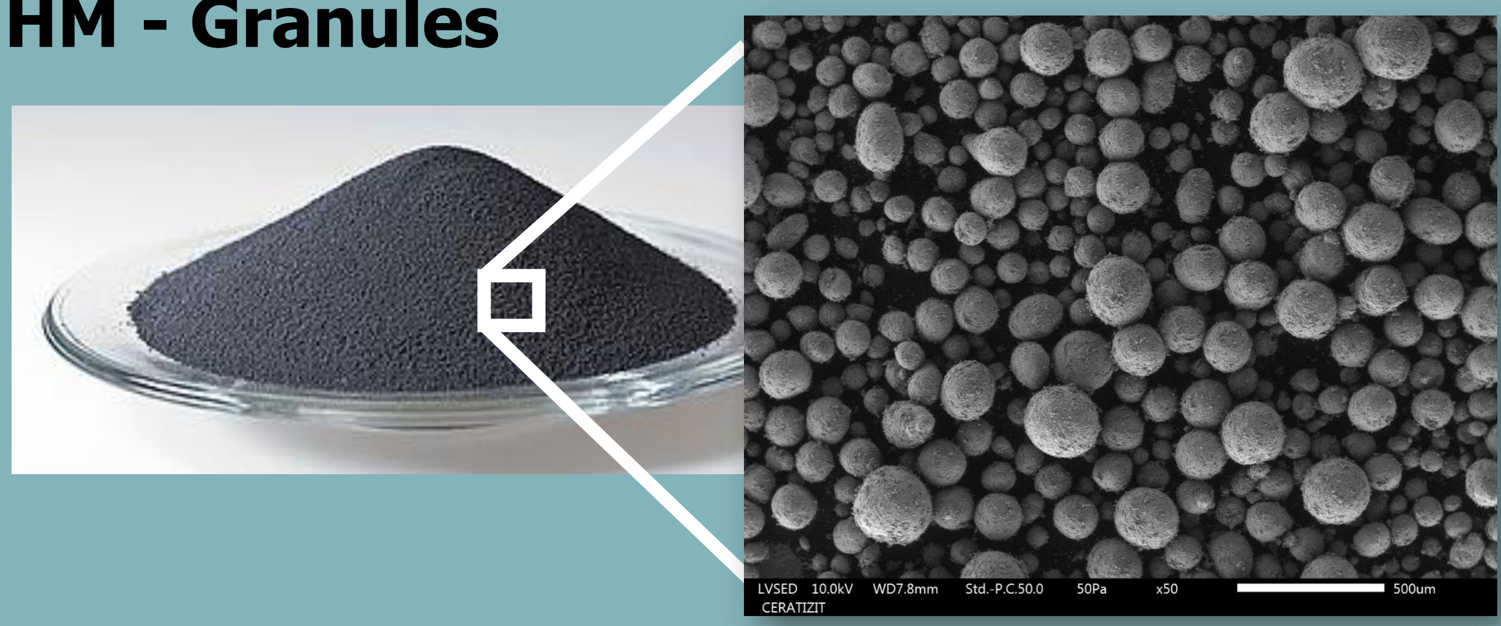
1. HM - Granules



Parameter influencing the filling process

- **Granules properties (e.g., roughness)**
- Parameters of the pressing process (e.g., filling shoe speed)
- Environment (e.g., humidity)

2. Objective

Understand the mass flow rate described by the Beverloo law [1] for hard metal granular materials considering interparticle forces and the angle of repose.

$$\dot{m} = C \cdot \rho \cdot \sqrt{g} \cdot (D - k \cdot d)^{2.5}$$

$$D_{eff} = D - k \cdot d$$

[1] W.A. Beverloo, H.A. Leniger, J. van de Velde, The flow of granular solids through orifices, Chem. Eng. Sci. 15 (1961) 260–269. https://doi.org/10.1016/0009-2509(61)85030-6.

3. Experimental approach

Measurements with sieved samples of

- Angle of repose α (friction coefficient μ)
- Mass flow rate $\dot{m}$ (Orifice diameters D of 2-8 mm)

Attractive forces between a HM-granule and a planar surface made of HM-granules with an atomic force microscope (AFM)

- Calculation of the granular Bond number Bo_g

$$Bo_g = \frac{\sum \vec{F}_c}{\vec{F}_g} \approx \frac{F_{vdW}}{F_g}$$

4. Results

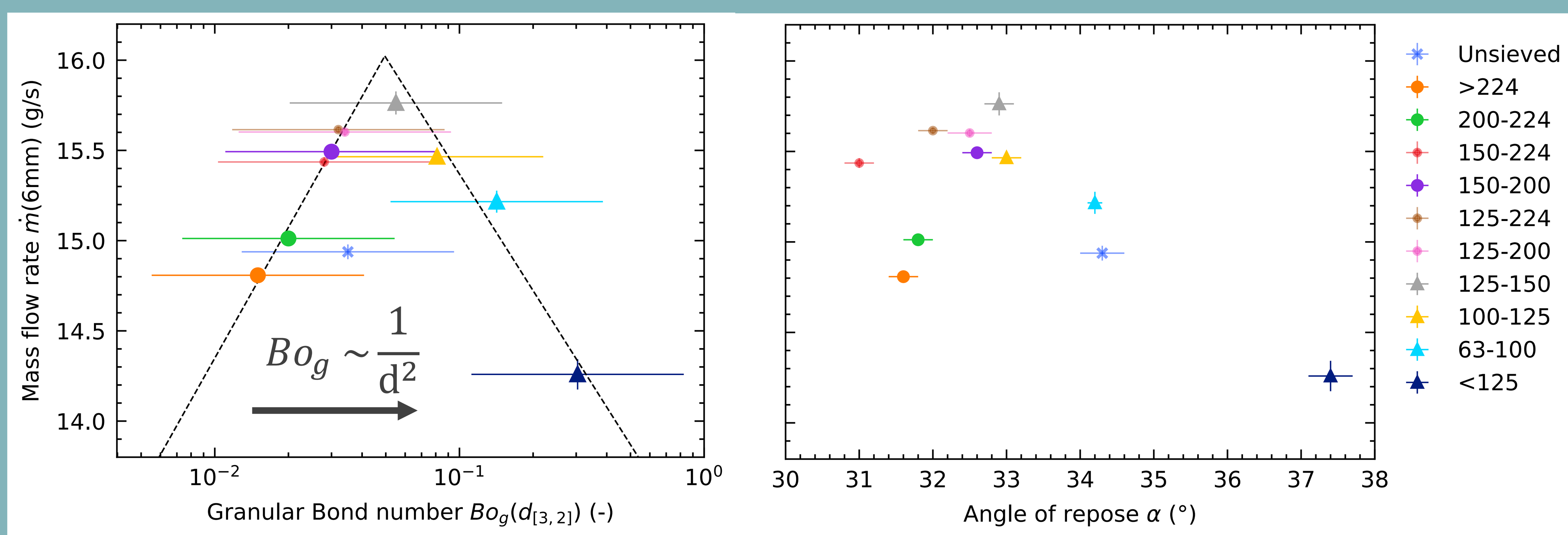
4.1 Two competing effects of gravitational and attractive forces by decreasing the mean diameter d yields a maximal mass flow rate [2]:

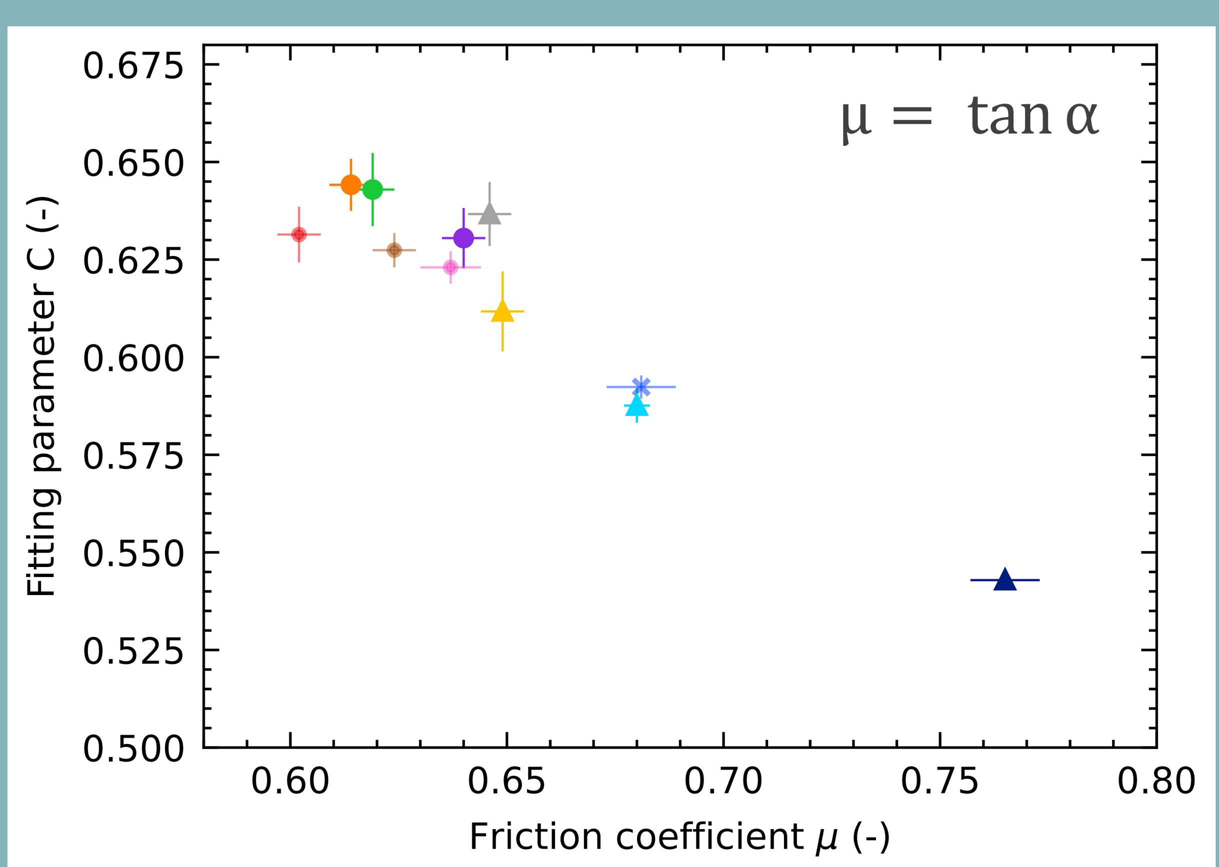
- Increase in granular Bond number Bo_g increases the mass flow rate $\dot{m}$ as the effective orifice diameter D_{eff} increases until a maximum is reached
- Further increase of the granular Bond number Bo_g decreases the mass flow rate $\dot{m}$ as the attractive forces become more dominant reducing the effective orifice diameter D_{eff}

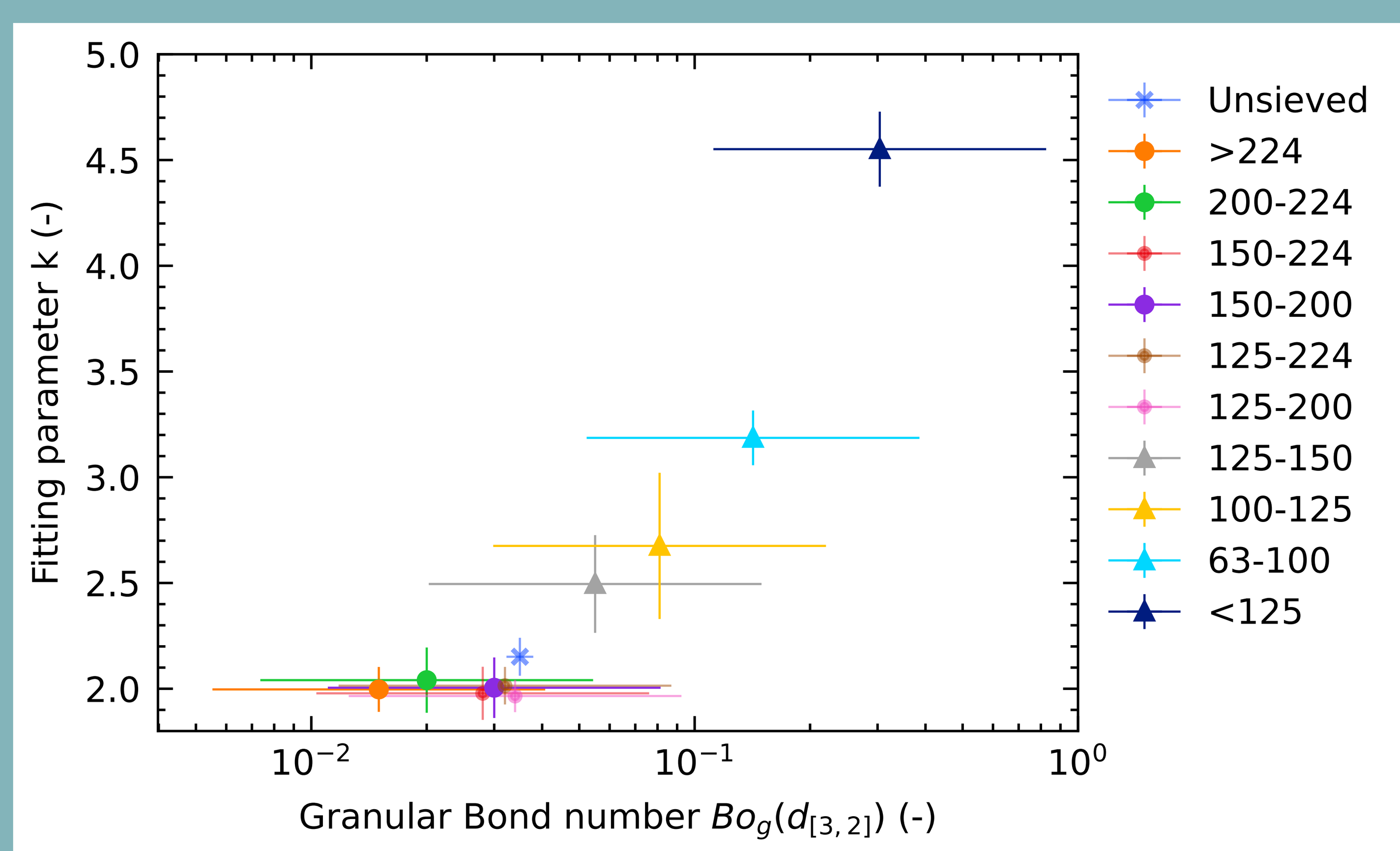
4.2 The maximal mass flow rate is found at the similar granular Bond number Bo_g positions

- Nearly independent of orifice diameter D

4.3 A low angle of repose does not imply high mass flow rates [2]







4.4 Parameters C and k inside the Beverloo law

- Increasing friction coefficient μ leads to decreasing fitting parameter C
- Attractive forces (granular Bond number Bo_g) mainly influence parameter k
  - Increase of the effective diameter (d_{eff} = kd)

[2] M. Just, A. Medina Peschiutta, F. Hippe, R. Useldinger, J. Baller, Gravitational mass flow measurements of various granular materials in relation to an extended Bond number, Int. J. Refract. Met. Hard Mater. 112 (2023) 106142. https://doi.org/10.1016/j.ijrmhm.2023.106142.

5. Conclusion

Attractive forces, expressed by the granular Bond number, and the friction coefficient directly affect the mass flow of hard metal granular materials. Optimizing both parameters maximizes the mass flow rate.

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