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DIATIC

Force on a Large Sphere Immersed in an Expanded Water-Fluidized Bed over a Wide Range of Voidage Values

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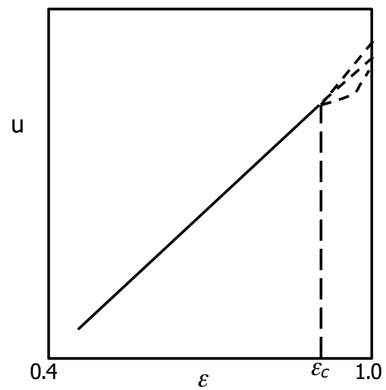
Force balance and segregation

- Forces on the different particles determines segregation
- Much relevant to performances of liquid-fluidized beds
  - Solids classification (e.g. mineral ores, coal beneficiation) (+)
  - Solids separation in waste recycling (+)
  - Homogeneity/mixing in bioreactors (–)
- Homogeneous expansion and hydrodynamics at $\varepsilon > {\sim}0.82$ show peculiarities[1]



① Epstein, N. Liquid-solid fluidization, in *Handbook of fluidization and fluid-particle systems.* (2003)

Hydrodynamic force measurements

- Typical assumption for large spheres:
  - analogy of the hydrodynamic force with the force on a buoyant body

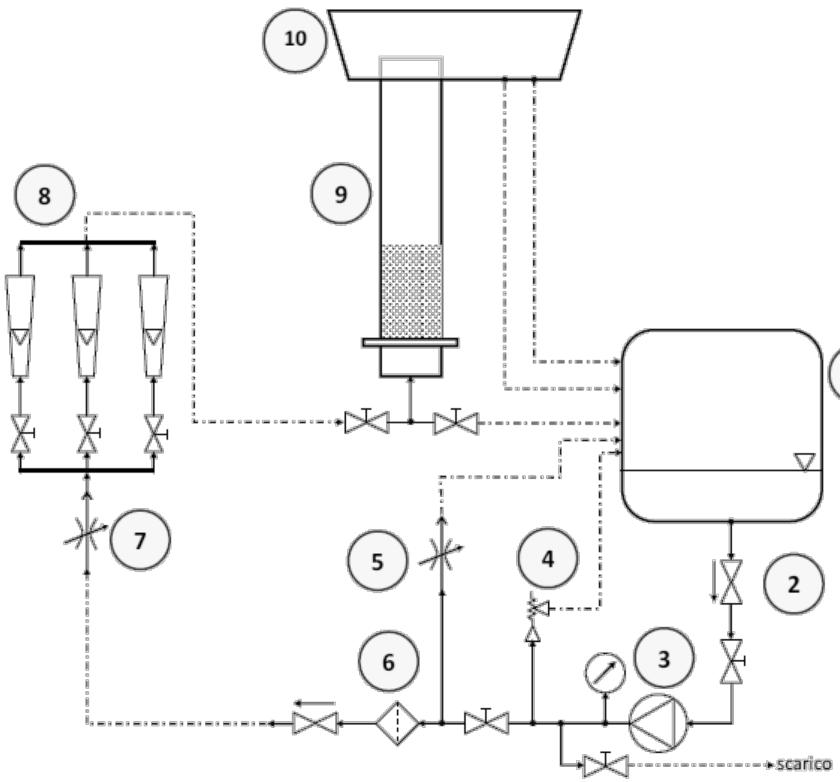
$$F = \rho V g$$

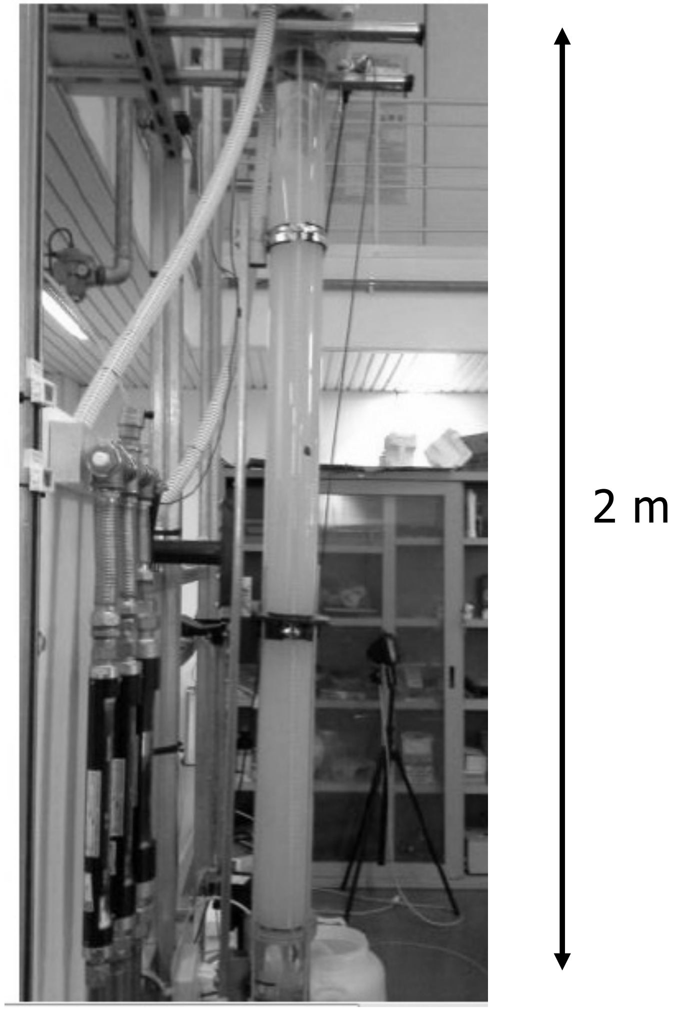
$$F = \left[\left(\rho_p - \rho\right)(1 - \varepsilon) + \rho\right] V g$$

- Aim: Experimentally characterize the force acting on a large sphere immersed in a suspension expanded over a high range of voidage

- Methods: float/sink tests and direct force measurement

Water-fluidization rig

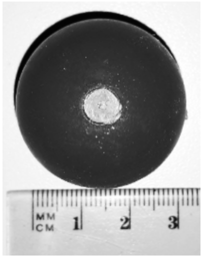




① water tank; ② one-way valve; ③ pump; ④ pressure safety valve; ⑤ by-pass valve; ⑥ filter; ⑦ control valve; ⑧ rotameters; ⑨ fluidization column (see photo); ⑩ discharge pan.

Float/sink tests

Plastic spheres containing variable amounts of small lead particles and filled with (PDMS) silicone, immersed in water-fluidized glass beads (613 μm av. diameter).



Prepared spheres:

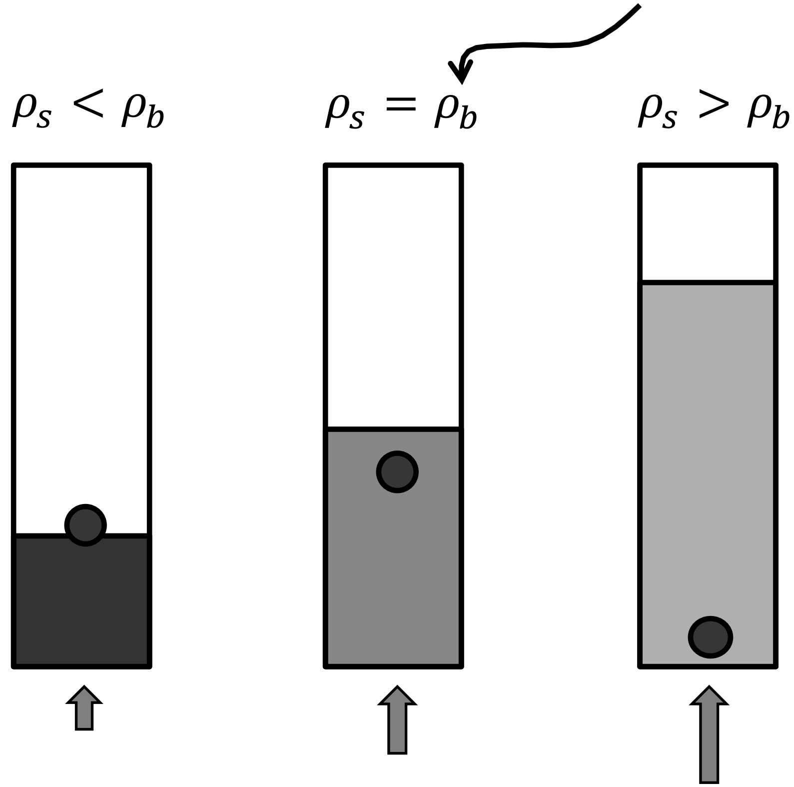
ID	*D* [cm]	ρ [kg/m³]
1	2.50	1481
2	3.16	1385
3	1.90	1257
4	1.90	1186
5	2.50	1175

Bed:

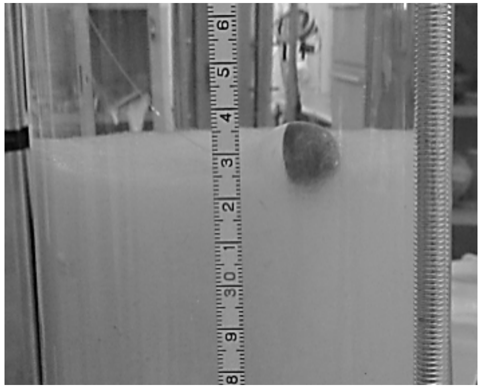
glass beads ($D = 613\ \mu m, \rho_s = 2500\ kg/m^3$)

FLOAT/SINK test

Equilibrium bed density $\rho_{b,eq}(\varepsilon)$

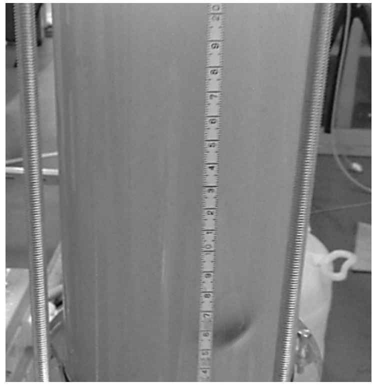


Float/sink tests



FLOAT

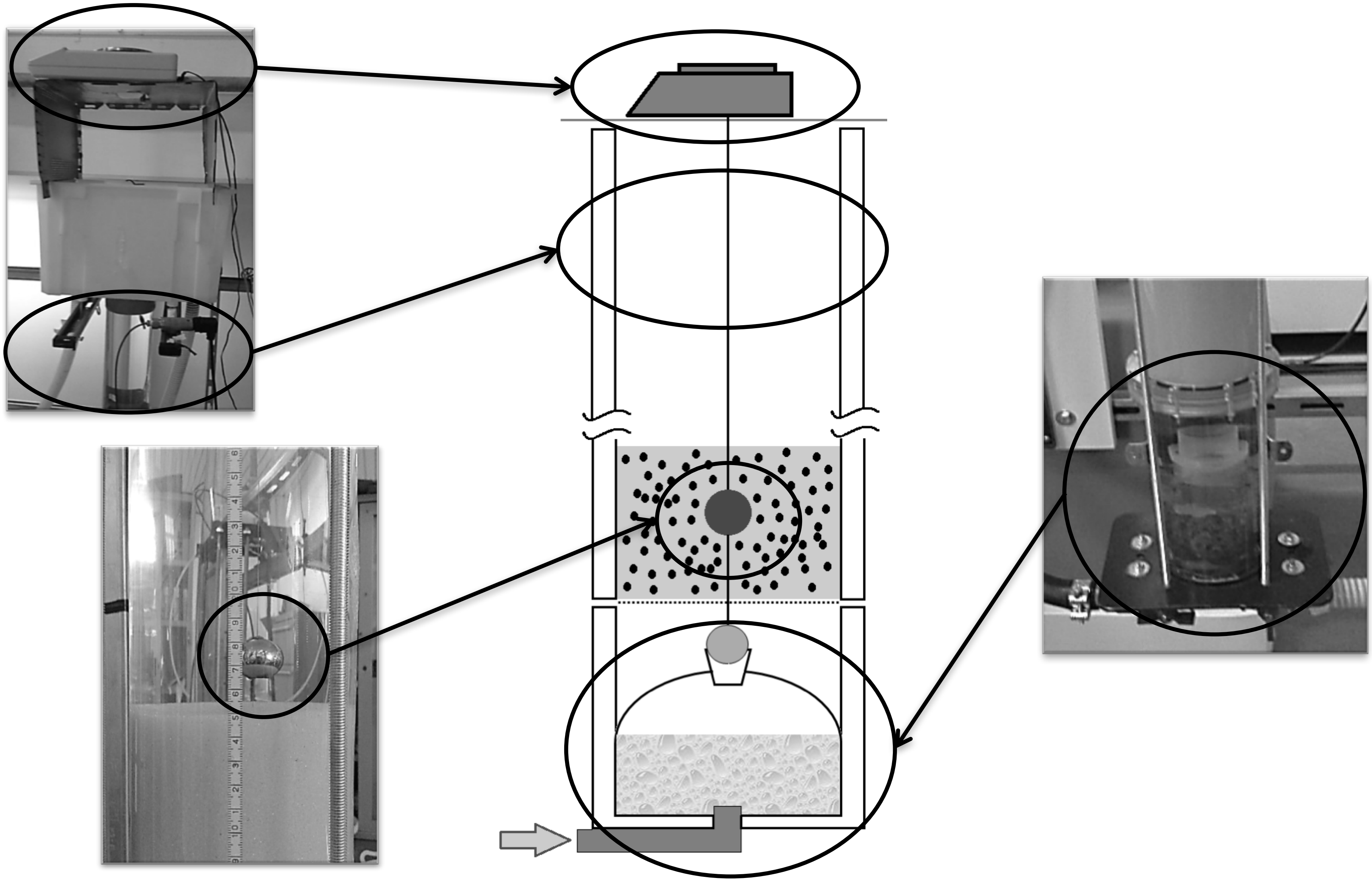
EQUILIBRIUM



SINK

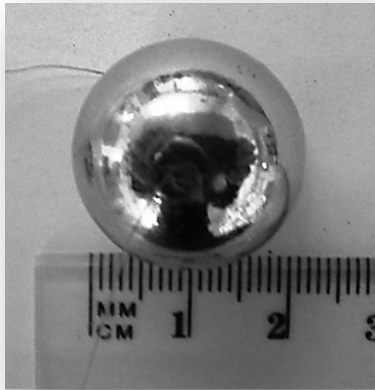
ID sphere	u [cm/s]	ε [-]	$\rho_{b,eq}$ [kg/m^3]	ρ_s [kg/m^3]	Relative difference %
1	1.9	0.64	1535	1481	3,5
2	3.4	0.76	1353	1385	-2,3
3	4.1	0.81	1284	1257	2,1
4	4.8	0.85	1221	1186	2,9
5	5.8	0.90	1145	1175	-2,6

Direct measurement setup



Direct force measurement

- Operating conditions



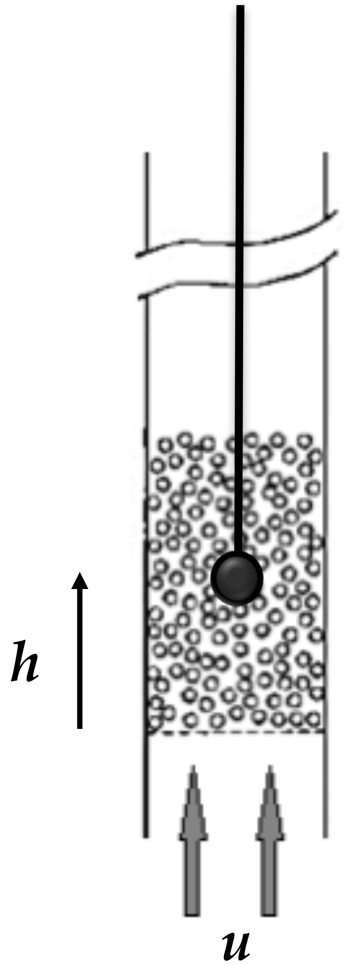
Metal alloy **sphere**: ($D_s = 2.1\ cm, \rho_s = 4850\ kg/m^3$)

Bed: glass beads ($\rho_s = 2500\ kg/m^3$)

1. $D_{avg} = 613\ \mu m$
2. $D_{avg} = 325\ \mu m$
3. $D_{avg} = 91\ \mu m$

Different sphere positions:

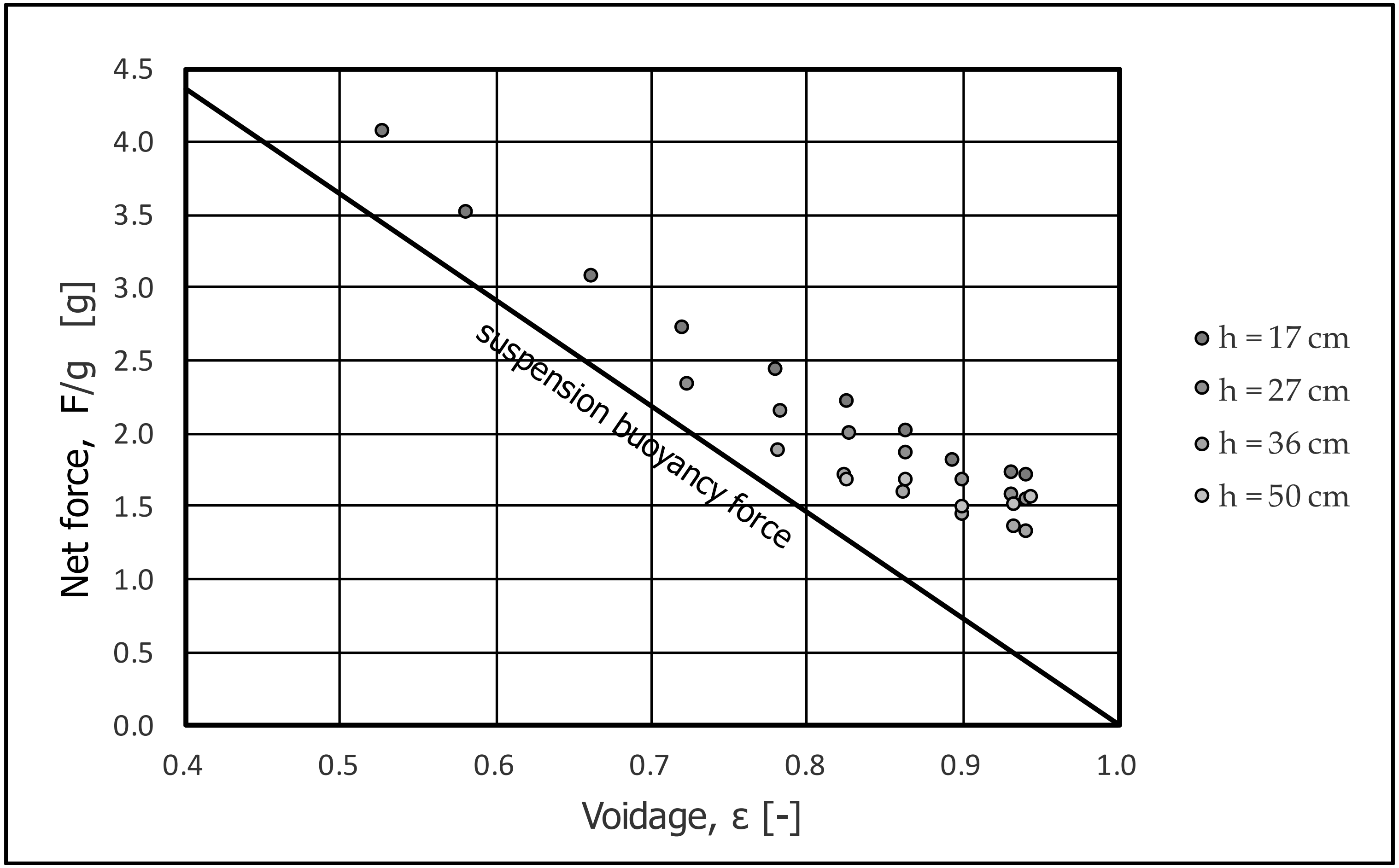
$$h = \begin{cases} 50\ cm \\ 36\ cm \\ 27\ cm \\ 17\ cm \end{cases}$$



Direct force measurement

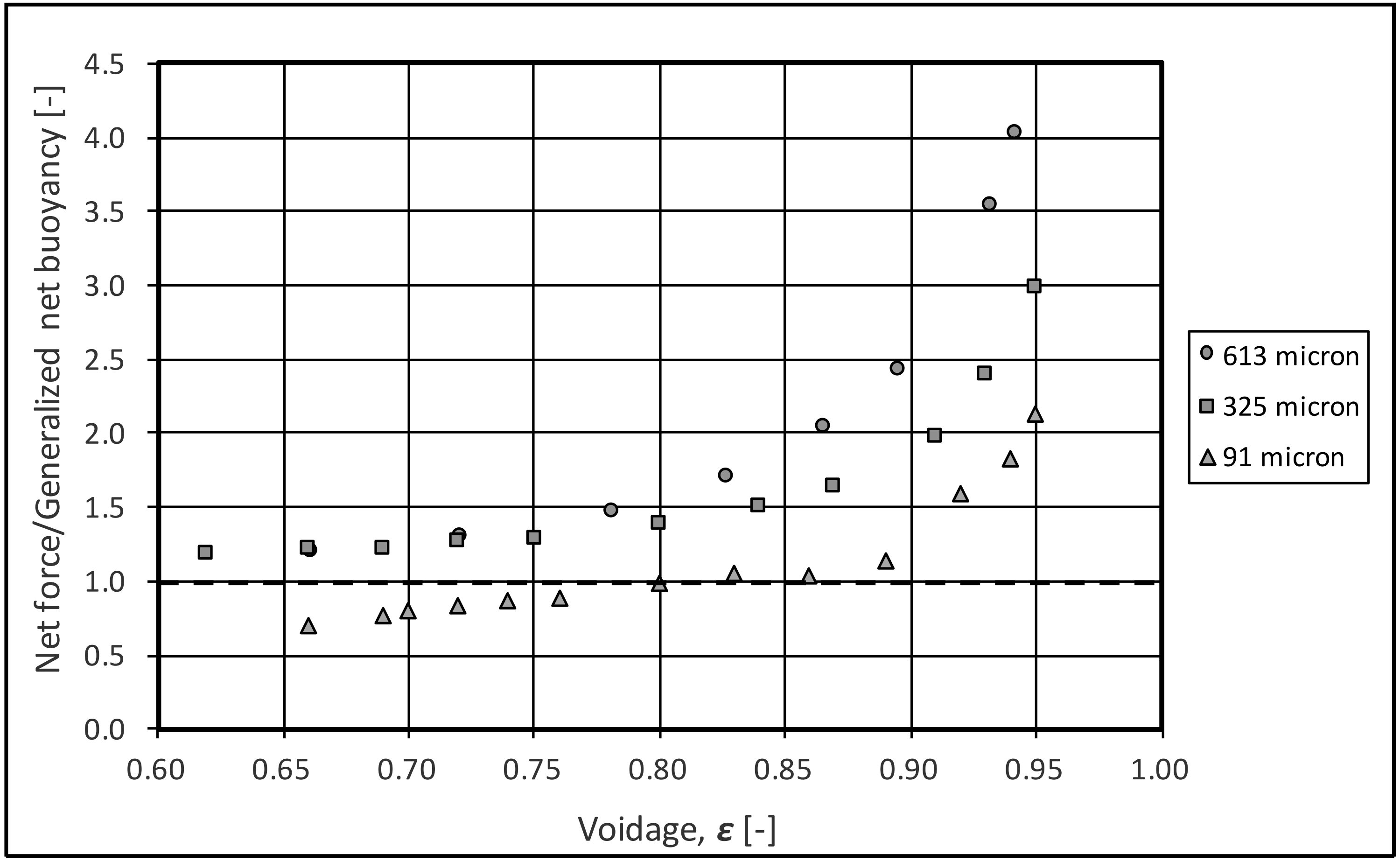
- Results: measured force (d_p = 613 μm)

(tare with the sphere immersed in water but outside the fluidized bed)



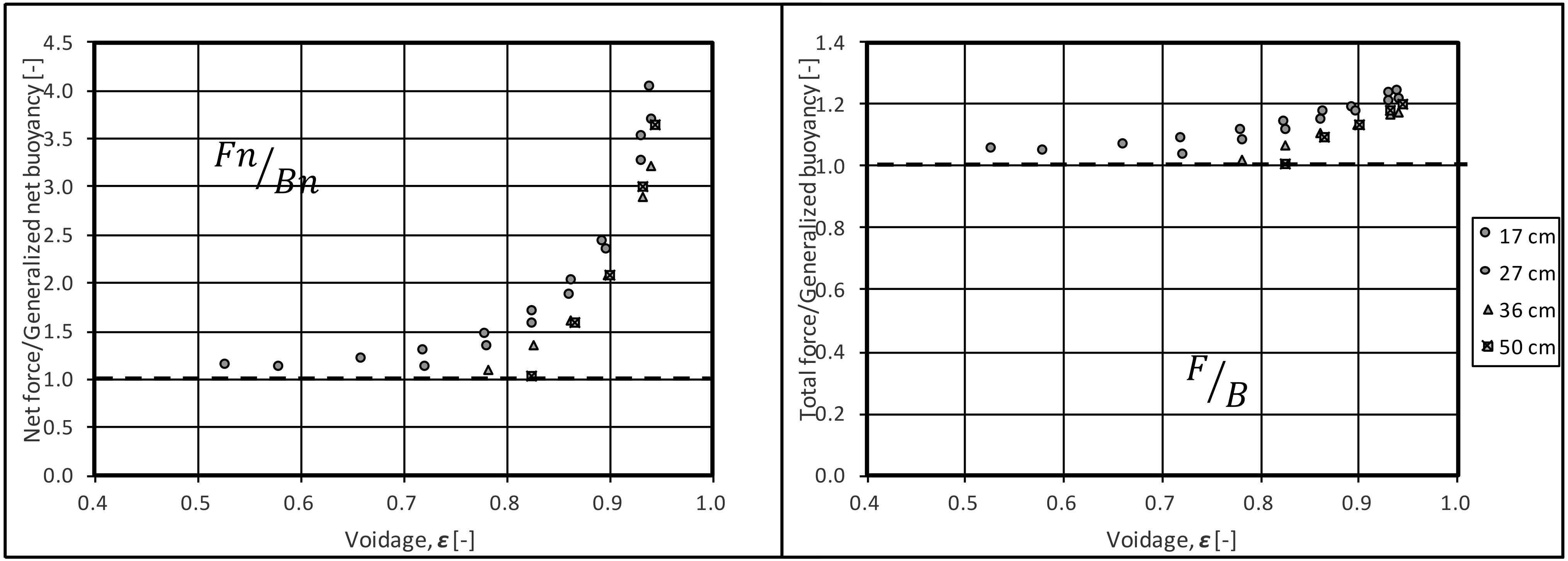
Direct force measurement

- Results: force ratio



Direct force measurement

- Results: force ratio

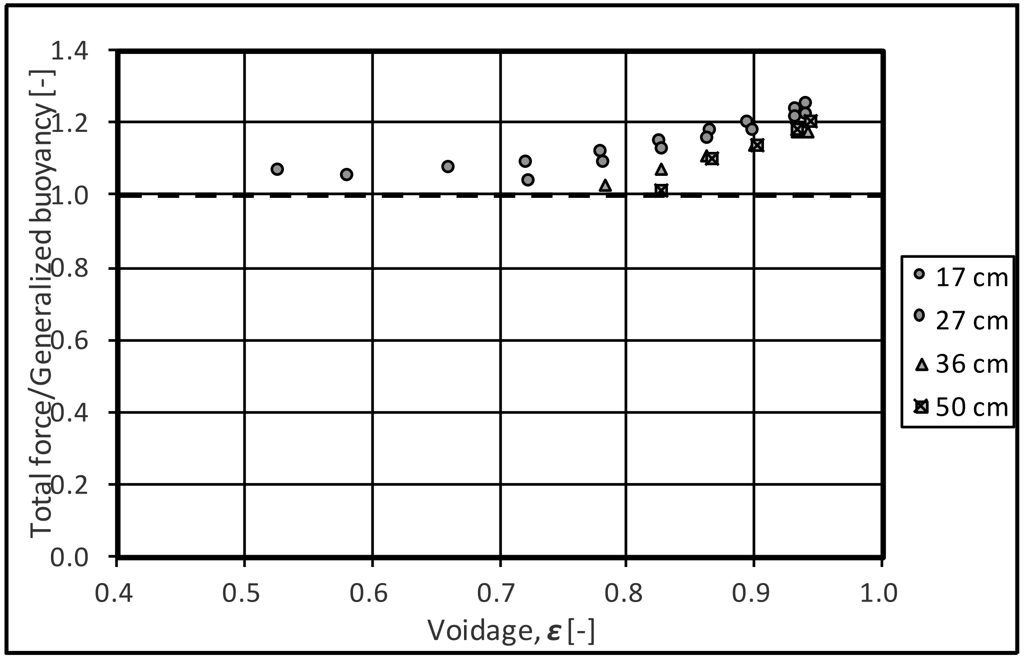


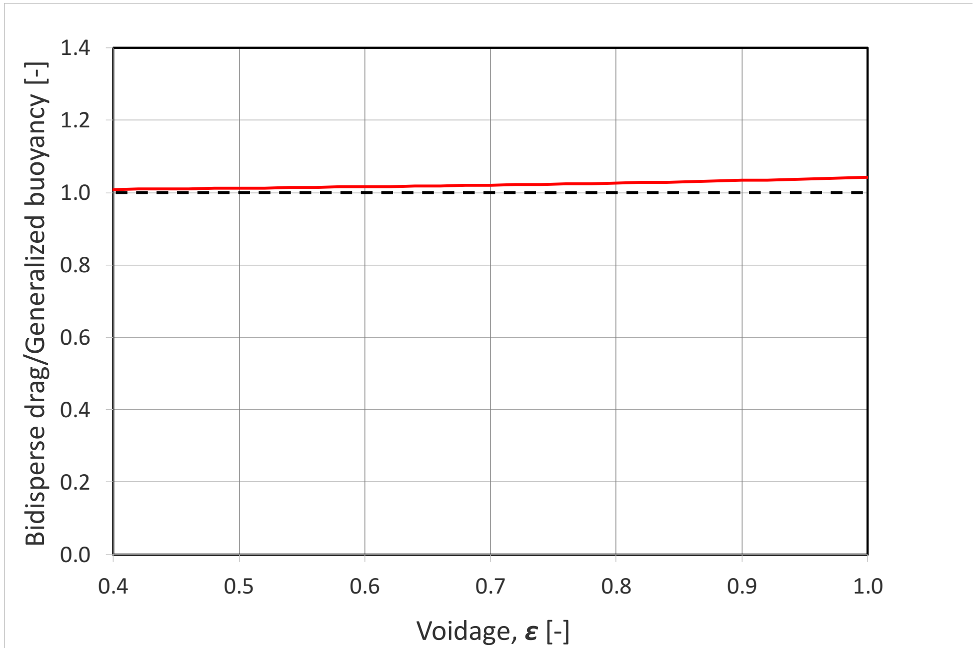
- ***Fn*** Net force: measured force (times g)
- ***F*** Total force: measured force + Archimedean buoyancy $(= \rho V g)$
- ***Bn*** Generalized net buoyancy: suspension *net* buoyancy $(= (\rho_p - \rho)(1-\varepsilon)Vg)$
- ***B*** Generalized buoyancy: suspension buoyancy $(= [(\rho_p - \rho)(1-\varepsilon) + \rho]Vg)$

Interpretation via drag force

- Is it possible to predict this deviation?

• ***Fn**** Bidisperse net force model[1]: drag + generalized net buoyancy
($Fn^* = \left[\varepsilon \frac{d}{D} + (1-\varepsilon)\right](\rho_p - \rho)Vg$)





The bidisperse drag captures the qualitative trend but quantitative agreement is not good

Conclusions

- Float/sink series of experiments on five spheres different for size and density have shown that the analogy with the buoyant sphere appears appropriate (within the experimental error), even at voidage as high as $\varepsilon = 0.9$;
- However, direct force measurements on sphere constrained along the axis showed significant deviations of the net force from the generalized buoyancy analogous at high voidage;
- Deviations are similar at different particle positions along bed height, but they are larger the bigger the bed particles;
- In terms of global force ratio, observed force values are in excess of 20% larger than the suspension generalized buoyancy values; interpretation in terms of the pure drag component on the sphere provides qualitative but not quantitative agreement.