Minimum fluidization velocity prediction for struvite particles using an upflow fluidized bed system

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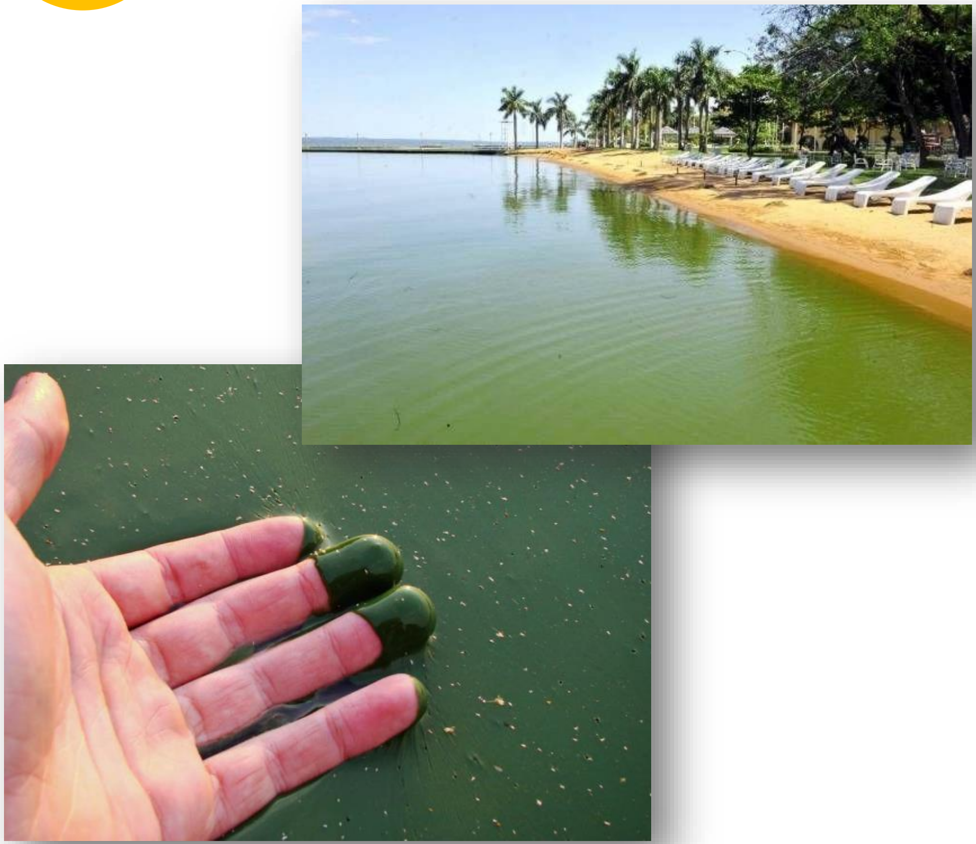
Nutrients in wastewater

"Agro-industrial wastewater streams, such as concentrated slaughterhouse wastewater, present high concentrations of nutrients that generally exceed those accepted for the discharge standards"

Negative Impacts of Nutrient Discharged

01 Eutrophication



Excessive richness of nutrients in bodies of water, causes a dense growth of plant life and death of animal life from lack of oxygen.

Negative Impacts of Nutrient Discharged

02 Crystalline deposits by uncontrolled deposition of phosphate salts in wastewater treatment systems

NEGATIVE IMPACTS OF NUTRIENT DISCHARGED

03 Phosphorus: an increasingly limited resource

"**Phosphorus** is the **limiting resource**, the bottleneck of agriculture and therefore of the **global food security**"

Main models developed estimate that the duration of P reserves will be **between 50 and 100 years**.

Consumption in 2015: 43.7 million MT [1]

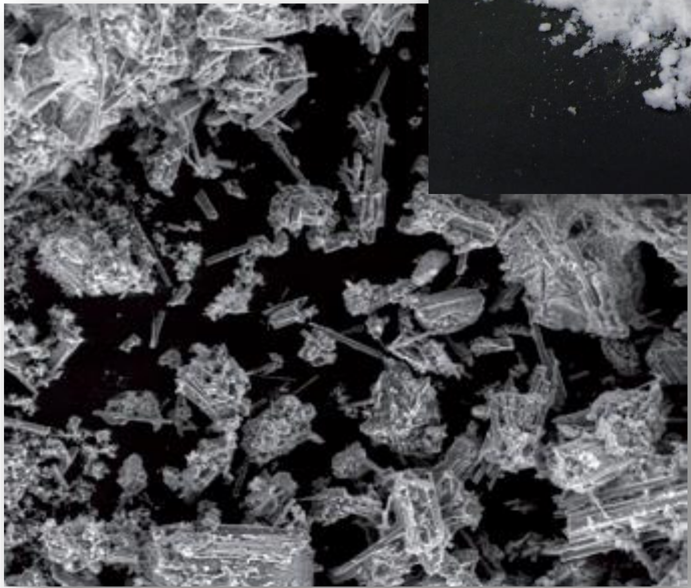
[1] USGS, Mineral commodity summaries. Technical report, U.S. Geological Survey, (2016) EE.UU.

Thus it is **necessary** to consider appropriate treatments that **reduce** the concentration of nutrients, seeking to ensure **economic, social** and **environmental** sustainability of these activities.

An alternative solution that allows the recovery of nutrients in wastewater is the crystallization as struvite.

STRUVITE PRECIPITATION

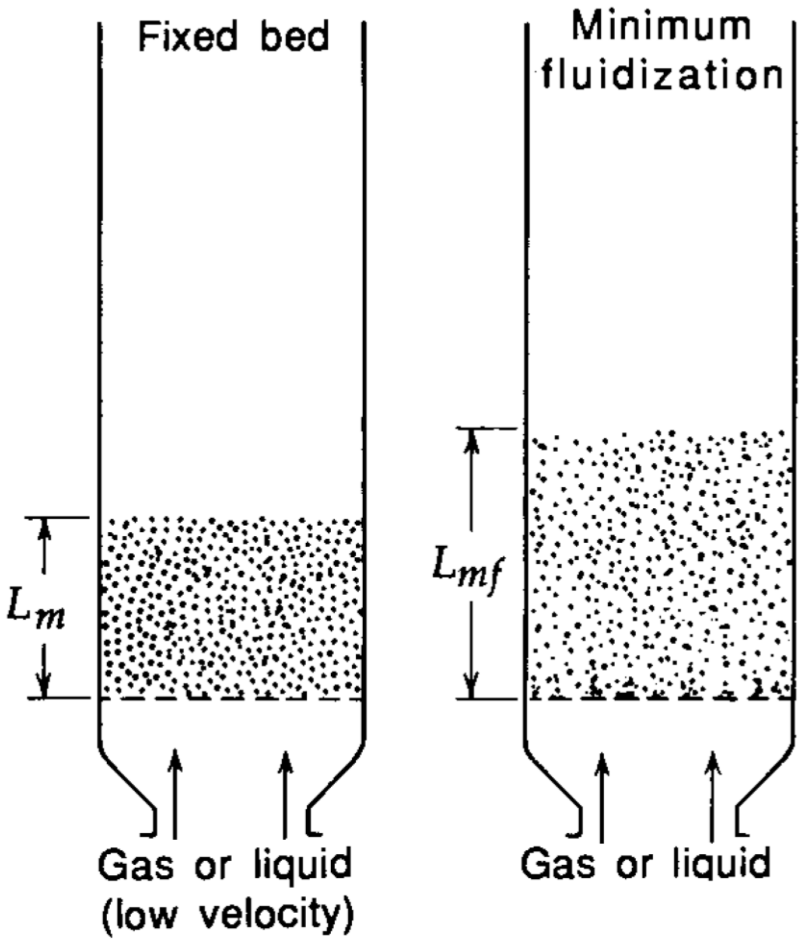
"Precipitation of ***struvite*** can be conceived as one of the main processes for recovery P and N from agro-industrial wastewater streams"

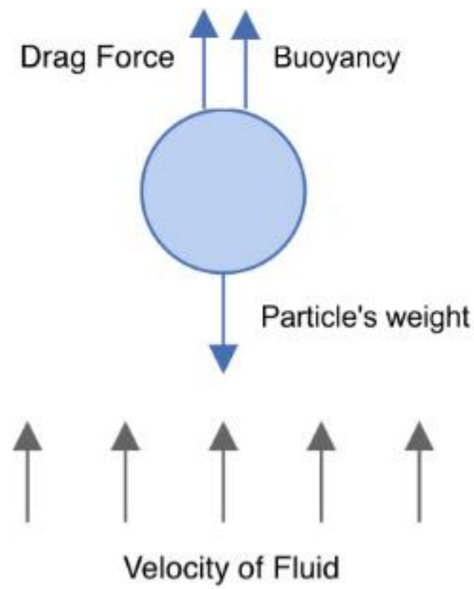


Struvite crystals

Magnesium ammonium phosphate hexahydrate: **$MgNH_4PO_4.6H_2O$**

MINIMUM FLUIDIZATION VELOCITY (u_{mf})





Voidage of the bed:

$$\varepsilon = \frac{\text{Volume of the voids}}{\text{Overall volume}} \qquad (1)$$

Ergun's Equation[2]

$$\frac{\Delta P_b}{L_{mf}} = \frac{150\, u_{mf}\, (1-\varepsilon_{mf})^2 \mu}{\varphi^2\, d_V^2\, \varepsilon_{mf}{}^3} + \frac{1{,}75\, \rho\, u_{mf}^2 (1-\varepsilon_{mf})}{\varphi\, d_V\, \varepsilon_{mf}{}^3} \quad (2)$$

$$\frac{\Delta P}{L_{mf}} = (1-\varepsilon_{mf})\, g\, (\rho - \rho_p) \quad (3)$$

where:
ΔP_b: Pressure drop across the bed.
L_{mf}: Bed's height.
u_{mf}: Minimum fluidization velocity.
ε_{mf}: Bed's void fraction.
μ: Fluid viscosity.
φ: Sphericity factor.
ρ: Fluid density.
ρ_p: Particle density.
d_V: Volume diameter.
d_S: Surface diameter.
d_P: Equivalent particle diameter.

Sphericity Factor:

$$\varphi = \left(\frac{d_V}{d_S}\right)^2 = \frac{d_P}{d_V} \quad (4)$$

[2] S. Ergun, Fluids flow through packed column, Chem. Eng. Prog., 48(2), (1952) p. 88–94.

Correlations to Predict the Minimum Fluidization Velocity

Table 1. Selected correlations to predict u_{mf}

Correlation	Equation	Id.
Wen and Yu (1966) [3]	$Re_{mf} = \sqrt{33{,}7^2 + 0{,}0408\ Ar} - 33{,}7$ (5)	C_1
Richardson (1971) [4]	$Re_{mf} = \sqrt{25{,}7^2 + 0{,}0365\ Ar} - 25{,}7$ (6)	C_2
Grace (1982) [5]	$Re_{mf} = \sqrt{27{,}2^2 + 0{,}0408\ Ar} - 27{,}2$ (7)	C_3
Delebarre (2004) [6]	$24{,}5\ Re_{mf}^2 + 29400\ \varepsilon_{mf}^2\ (1-\varepsilon)\ Re_{mf} = Ar$ (8)	C_4
Xu (2008) [7]	$Re_{mf}^2 + \frac{85{,}71\ (1-\varepsilon_{mf})}{\varphi_s} Re_{mf} = 0{,}57\ \varphi_s\ \varepsilon_{mf}^3\ Ar + 4{,}79\ .\ 10^{-9}\ \frac{\varphi_s\ \varepsilon_{mf}^{0{,}52}\ \rho_g\ d_p}{L_0\ \mu_g^2}$ (9)	C_5

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[3] C.Y. Wen and Y.H. Yu, A generalized method for predicting the minimum fluidization velocity. AIChE Journal, 12(3), (1966) pp. 610-612.
[4] J.F. Richardson, Incipient fluidization and particulate systems, Fluidization, (1971) pp. 26-64.
[5] J.R. Grace, Fluidized bed hydrodynamics, Handbook of multiphase systems, (1982) p. 5.

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[6] A. Delebarre, Revisiting the Wen and Yu equations for minimum fluidization velocity prediction, Chemical engineering research and design, 82(5), (2004) pp. 587-590.

Correlations to Predict the Minimum Fluidization Velocity

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[7] C.C. Xu and J. Zhu, Prediction of the minimum fluidization velocity for fine particles of various degrees of cohesiveness. Chemical Engineering Communications, 196(4), (2008) pp. 499-517.

Struvite preparation

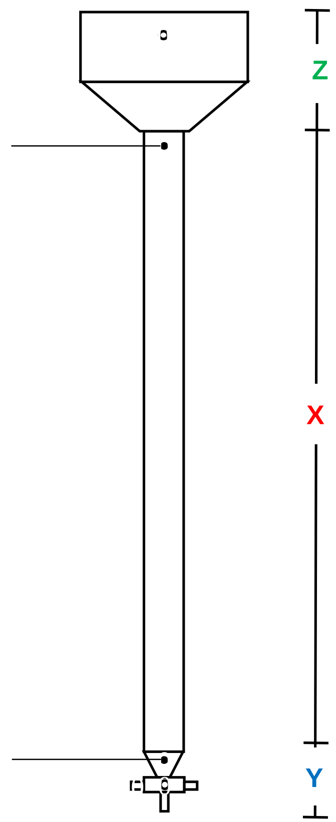
$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \rightleftarrows MgNH_4PO_4.6H_2O$$

STRUVITE PREPARATION

Table 2. Sieve diameter for assayed struvite particles

Identification	Mesh	d_{Sieve} (mm)
L	10 – 18	1,000 – 2,000
M	18 – 35	0,500 – 1,000
S	35 – 45	0,355 – 0,500

Bench-Scale Upflow Fluidized System



Dimensions:

X:

D_i=6 cm, h=100 cm;

Y:

D_i (top)=6 cm

D_i (bottom)=2 cm

h=10 cm

Z:

D_i (top)=25 cm

D_i (bottom)=6 cm

h=10 cm.

Figure 1. Bench-scale upflow system.

Bed Pressure-Drop

$$\Delta P_b = \Delta P - \Delta P_d \quad (10)$$

Bed Pressure-Drop

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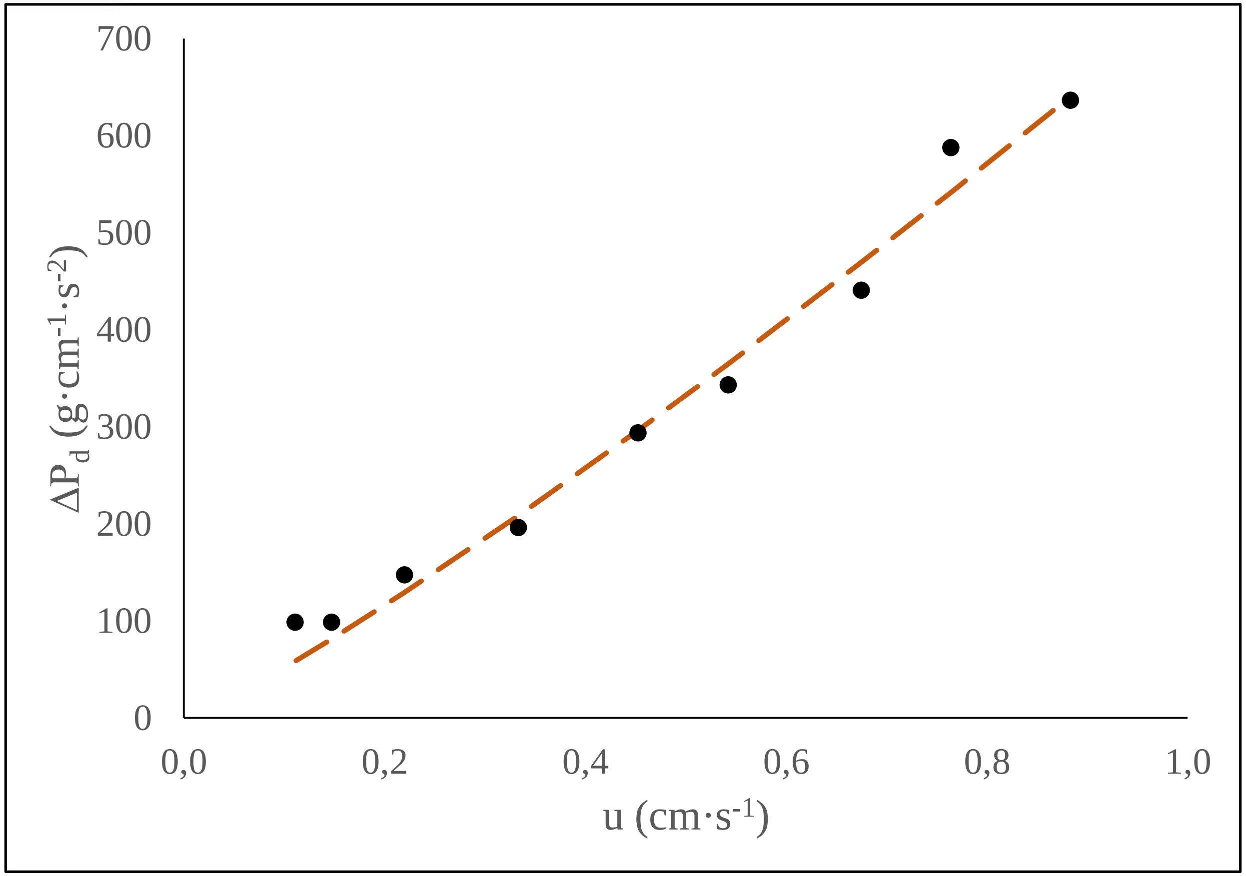
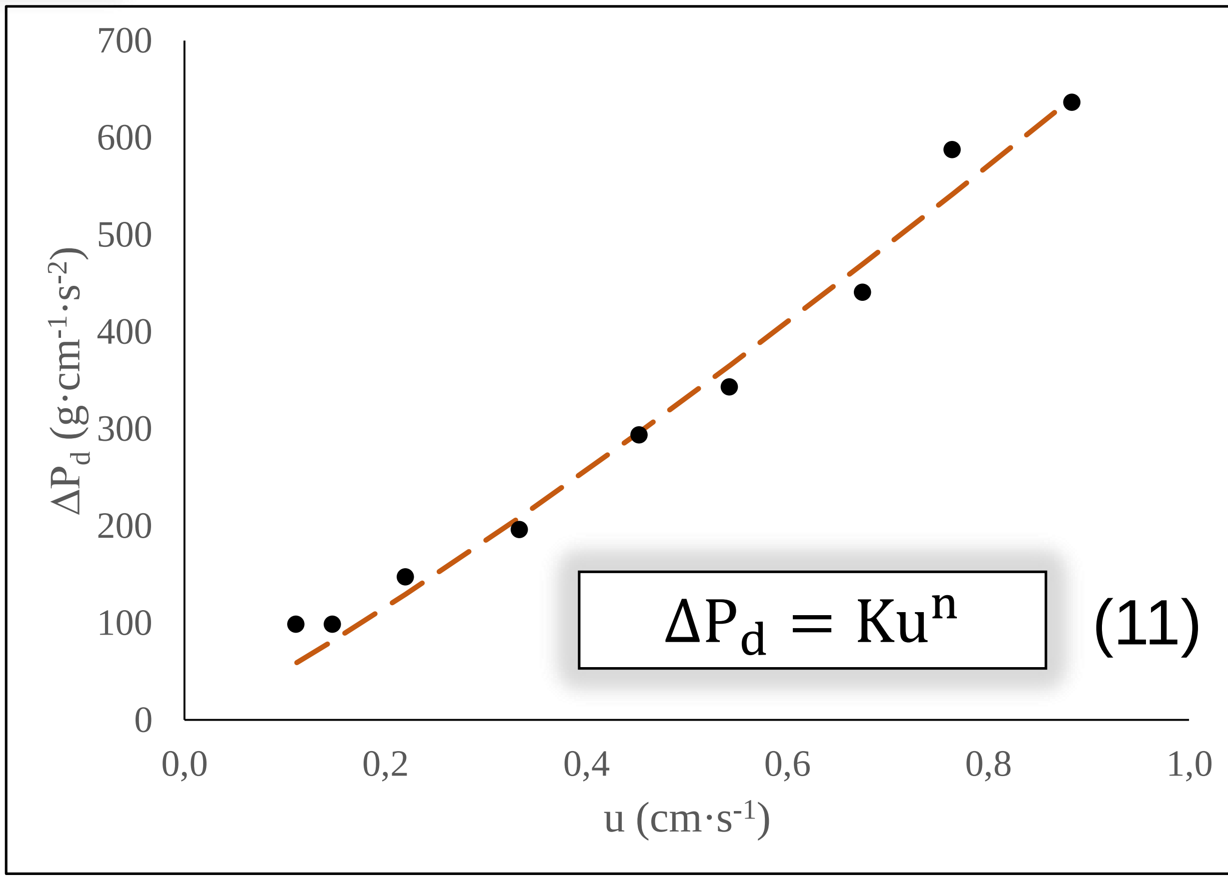


Figure 2. Variation of the distributor pressure-drop with superficial water velocity.

Bed Pressure-Drop

$$\Delta P_b = \Delta P - \Delta P_d \quad (10)$$



$$\Delta P_d = Ku^n \quad (11)$$

Figure 2. Variation of the distributor pressure-drop with superficial water velocity.

Bed Pressure-Drop

$$\Delta P_b = \Delta P - \Delta P_d \quad (10)$$

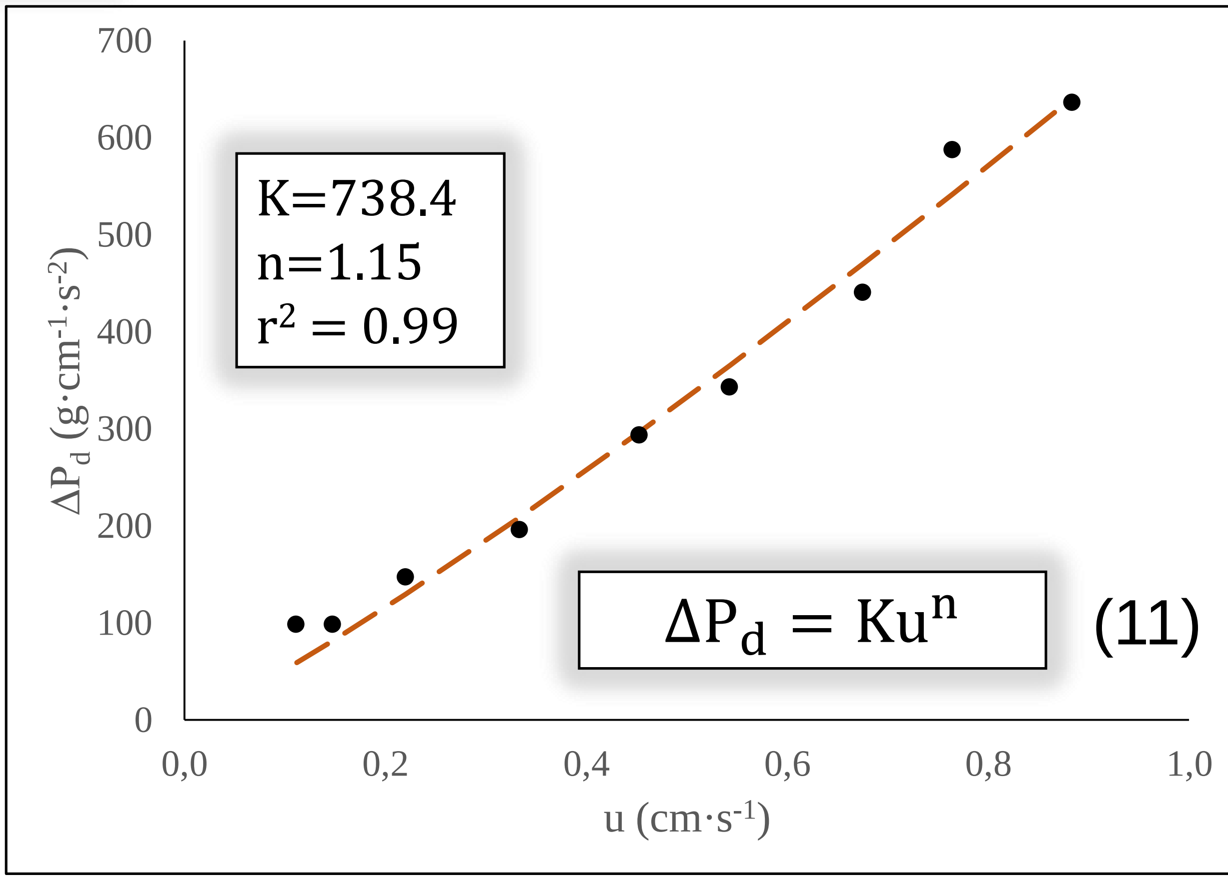


Figure 2. Variation of the distributor pressure-drop with superficial water velocity.

Minimum Fluidization Velocity Determination

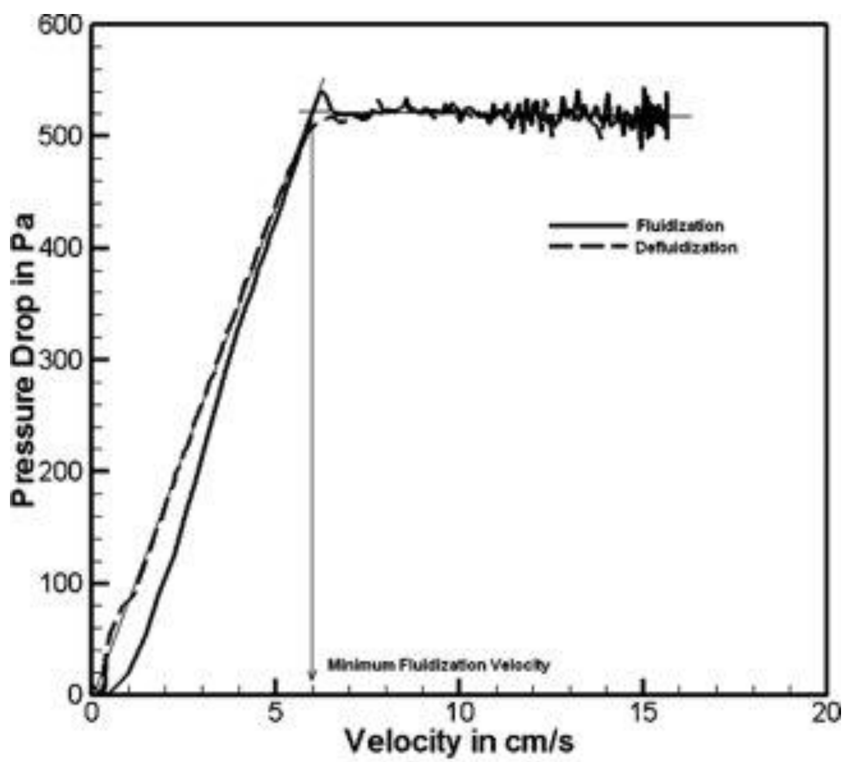


Figure 3. Minimum fluidization velocity determination.

Minimum Fluidization Velocity Determination

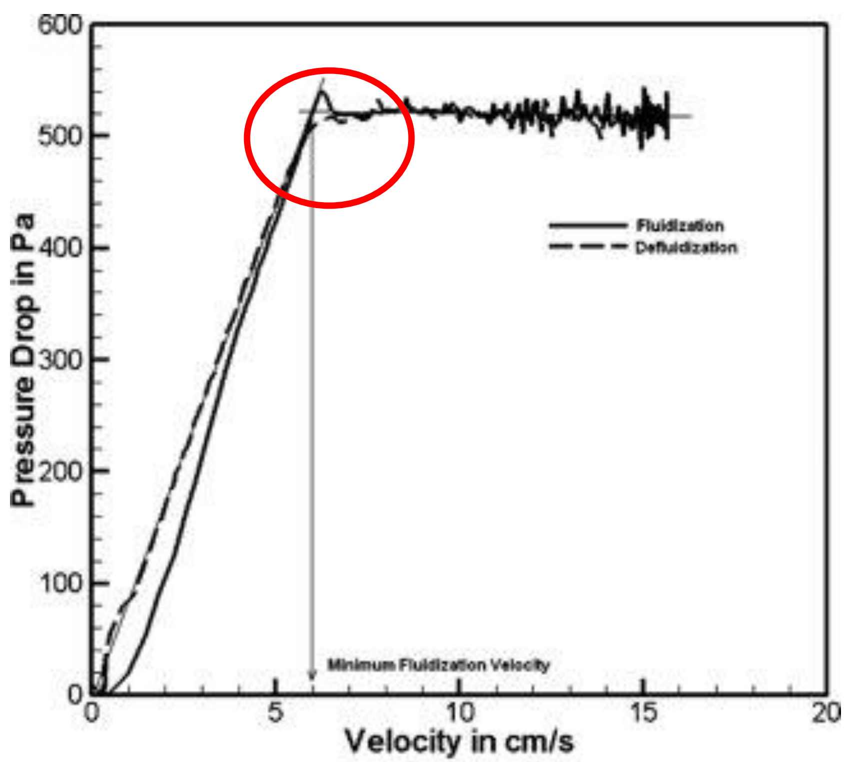
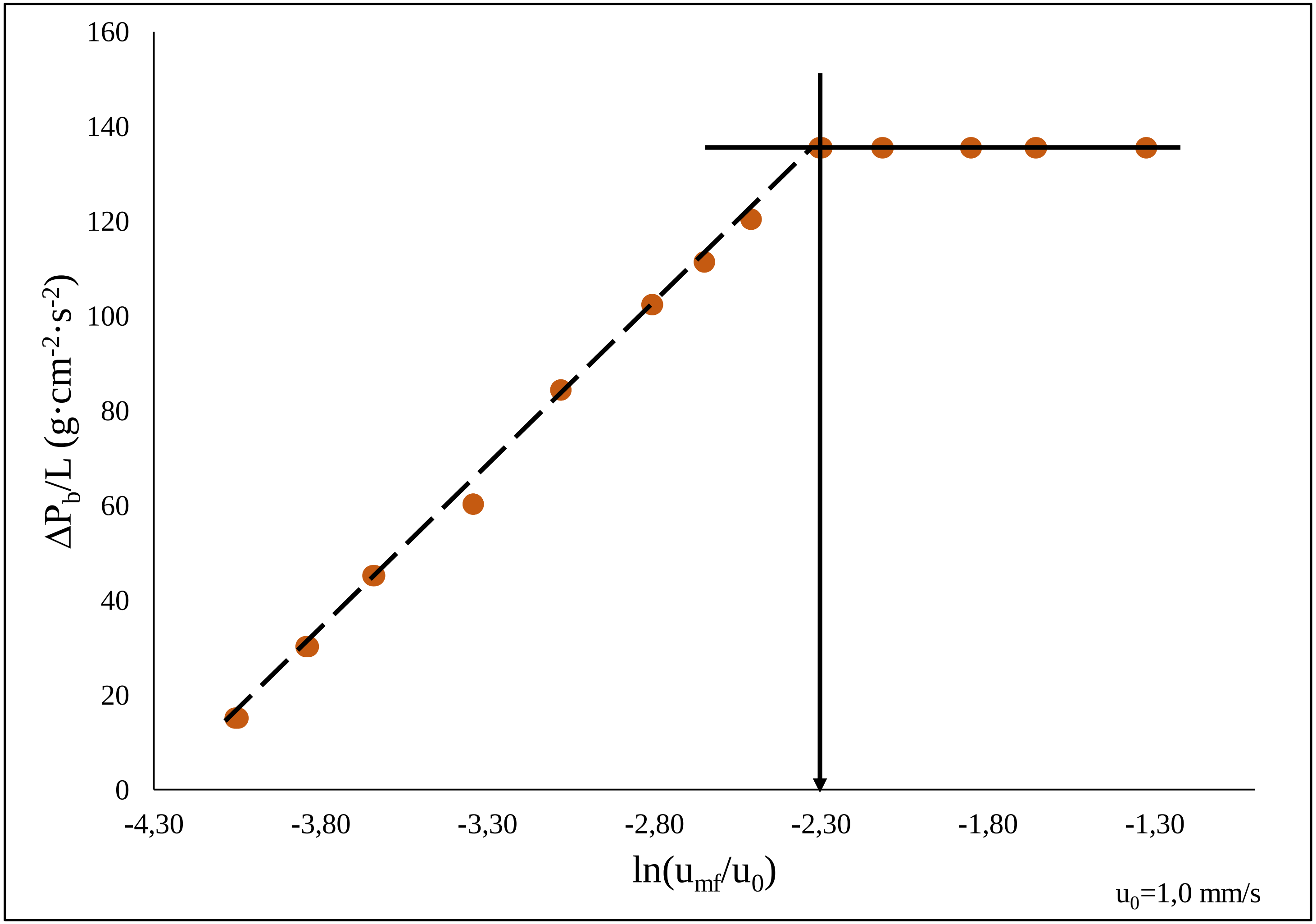


Figure 3. Minimum fluidization velocity determination.

Minimum fluidization velocity: Comparision Results



Size: L

m_b = 91 g
L_{mf} = 6,5 cm
ε_{mf} = 0,71

Figure 4. Variation of bed pressure-drop with superficial water velocity for L size class.

Minimum fluidization velocity: Comparision Results

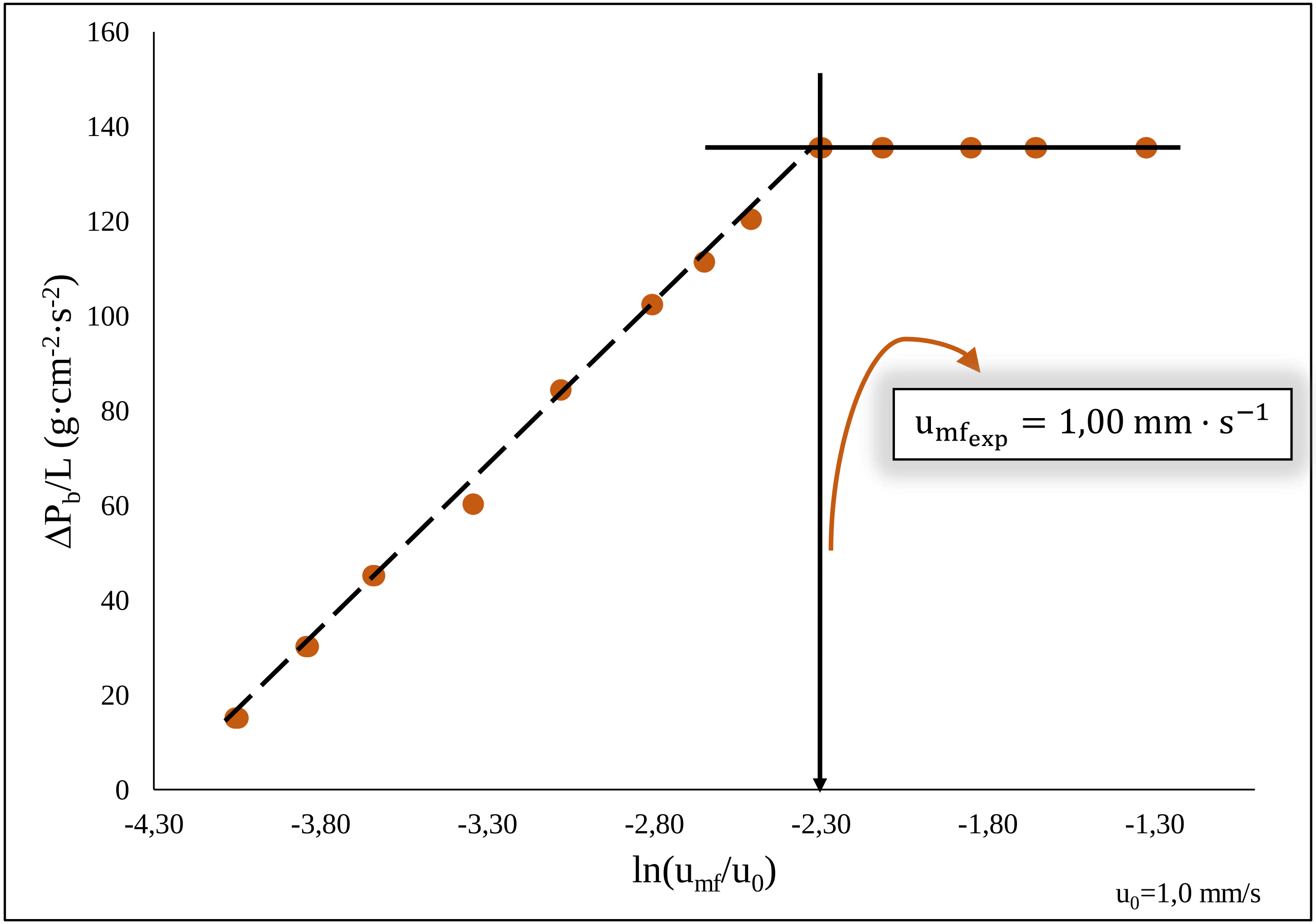


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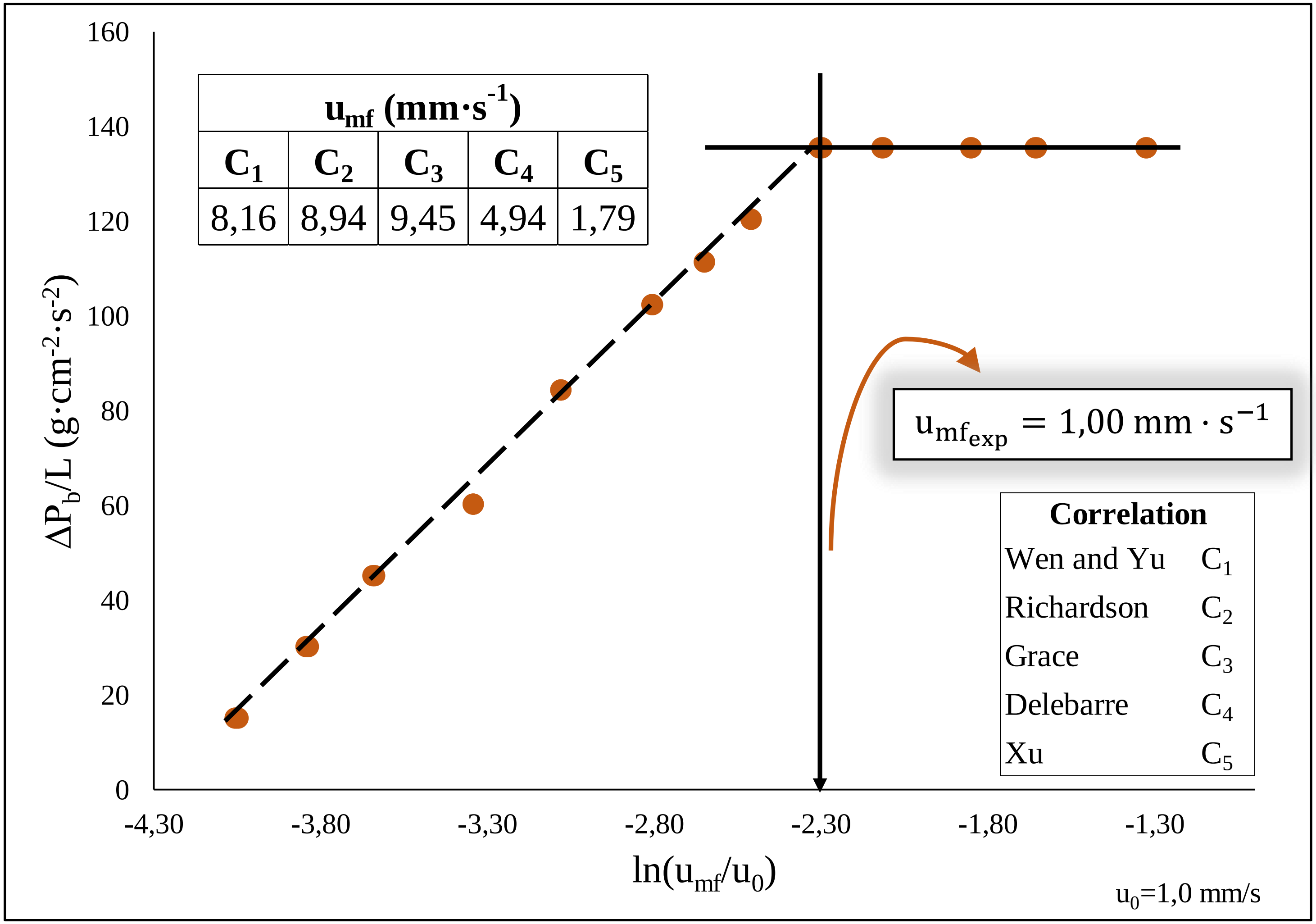
Figure 4. Variation of bed pressure-drop with superficial water velocity for L size class.

MINIMUM FLUIDIZATION VELOCITY: COMPARISION RESULTS



u_{mf} (mm·s^{-1})				
C_1	C_2	C_3	C_4	C_5
8,16	8,94	9,45	4,94	1,79

Correlation	
Wen and Yu	C_1
Richardson	C_2
Grace	C_3
Delebarre	C_4
Xu	C_5

Size: L

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L_{mf} = 6,5 cm
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Figure 4. Variation of bed pressure-drop with superficial water velocity for L size class.

Minimum Fluidization Velocity: Comparision Results

Size: M

m_b = 94 g
L_{mf} = 7,6 cm
ε_{mf} = 0,56

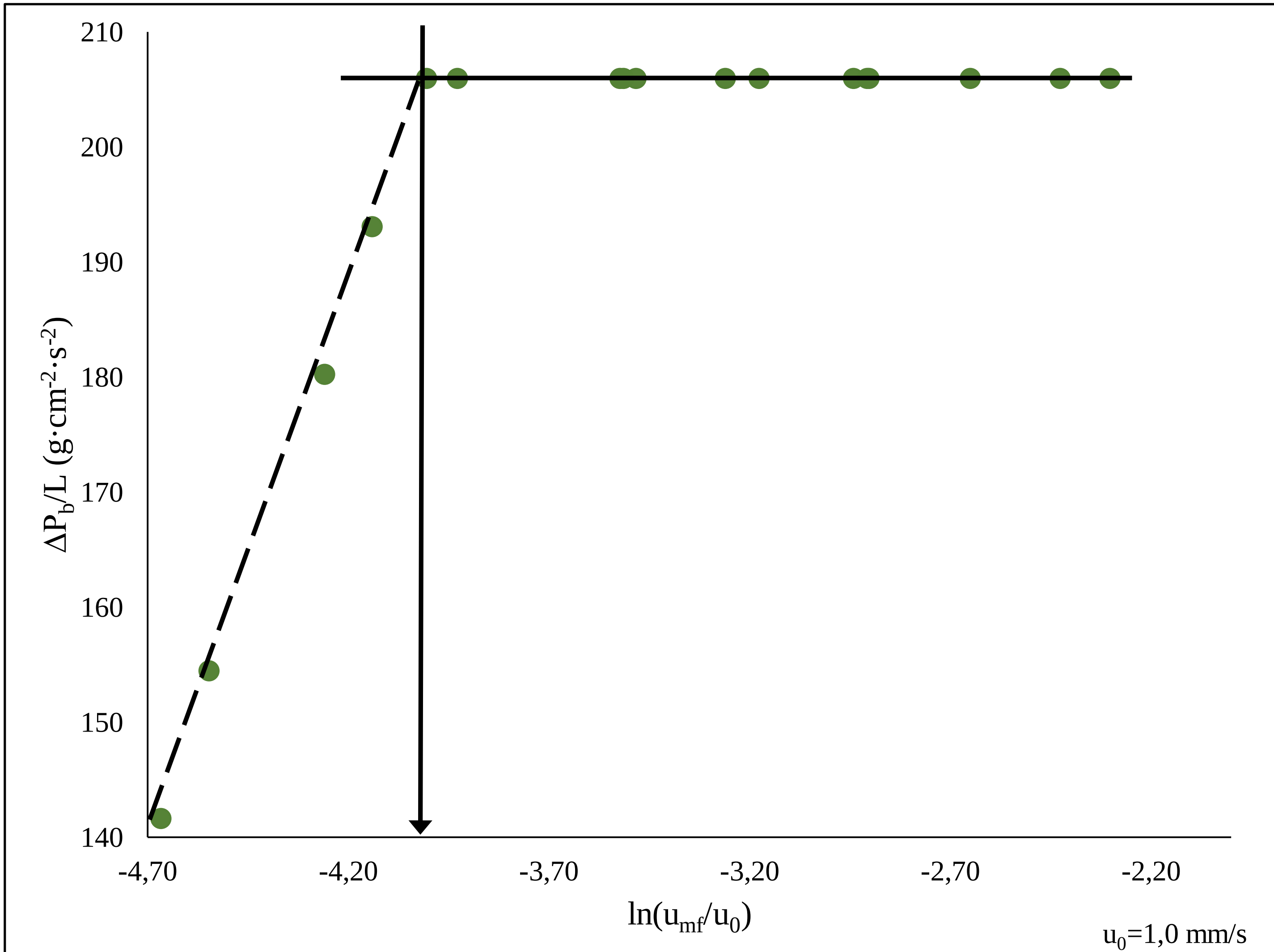

Figure 5. Variation of bed pressure-drop with superficial water velocity for M size class.

Minimum Fluidization Velocity: Comparision Results

Size: M

m_b = 94 g
L_{mf} = 7,6 cm
ε_{mf} = 0,56

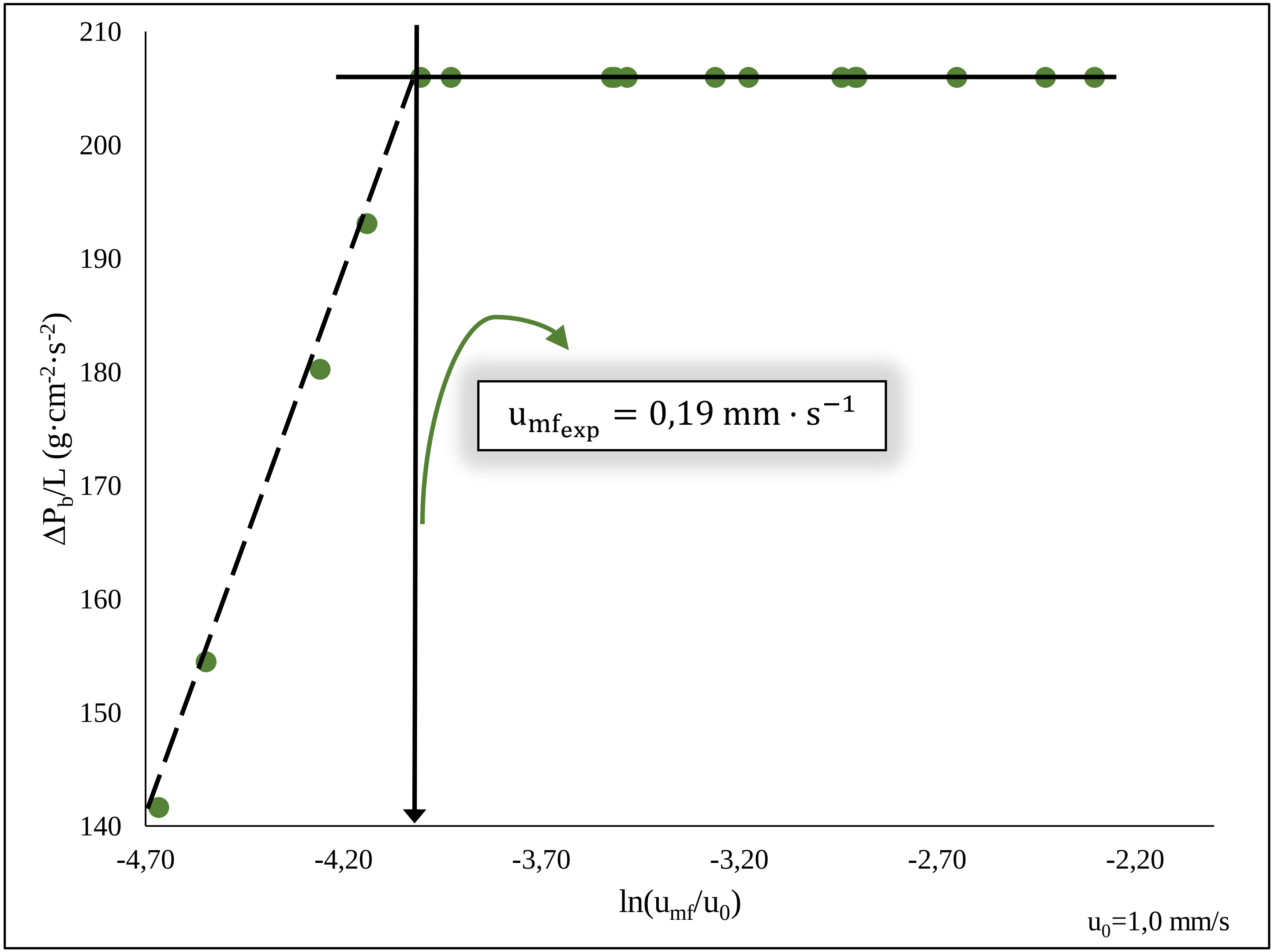

Figure 5. Variation of bed pressure-drop with superficial water velocity for M size class.

Minimum Fluidization Velocity: Comparision Results

Size: M

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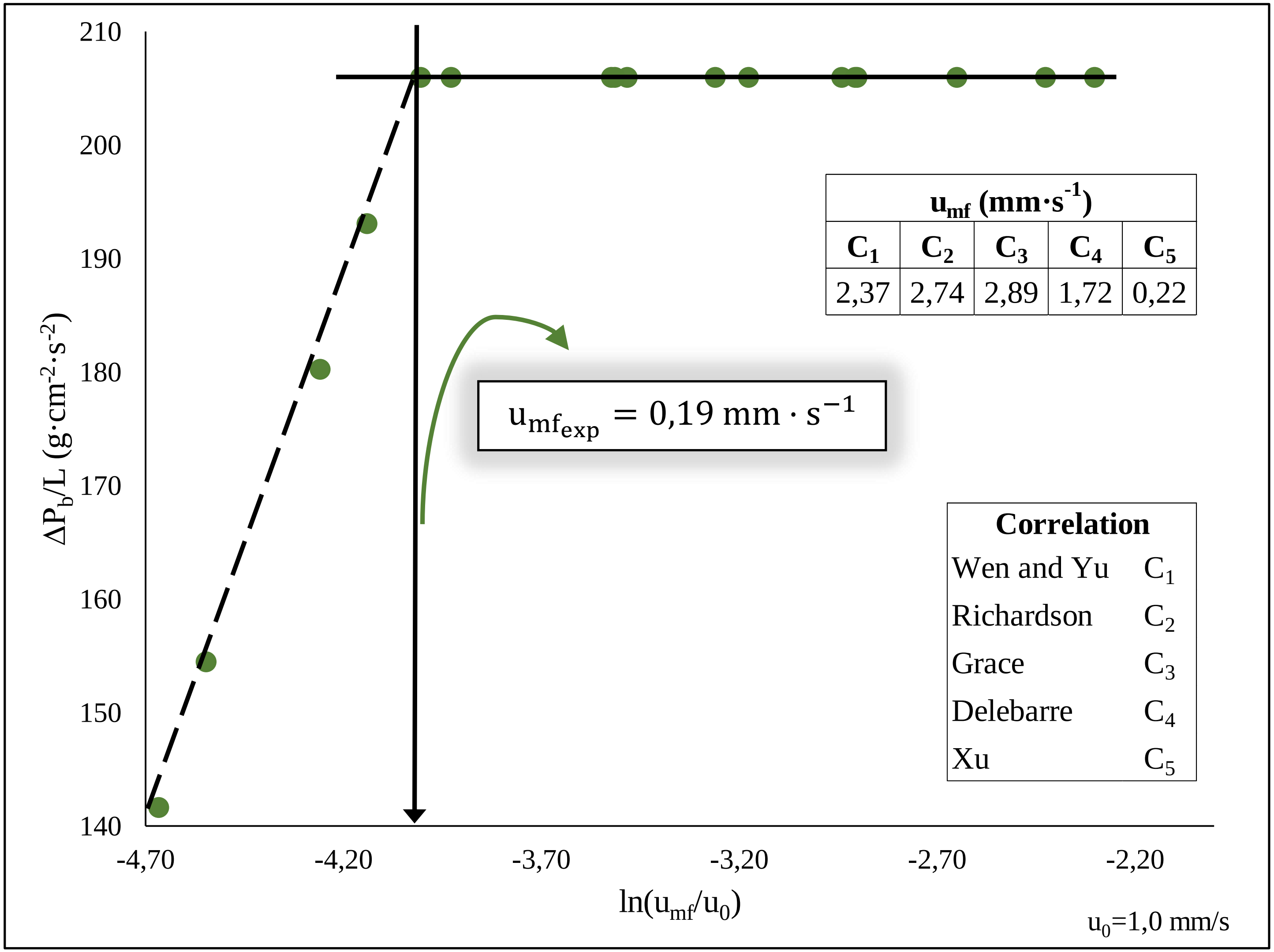
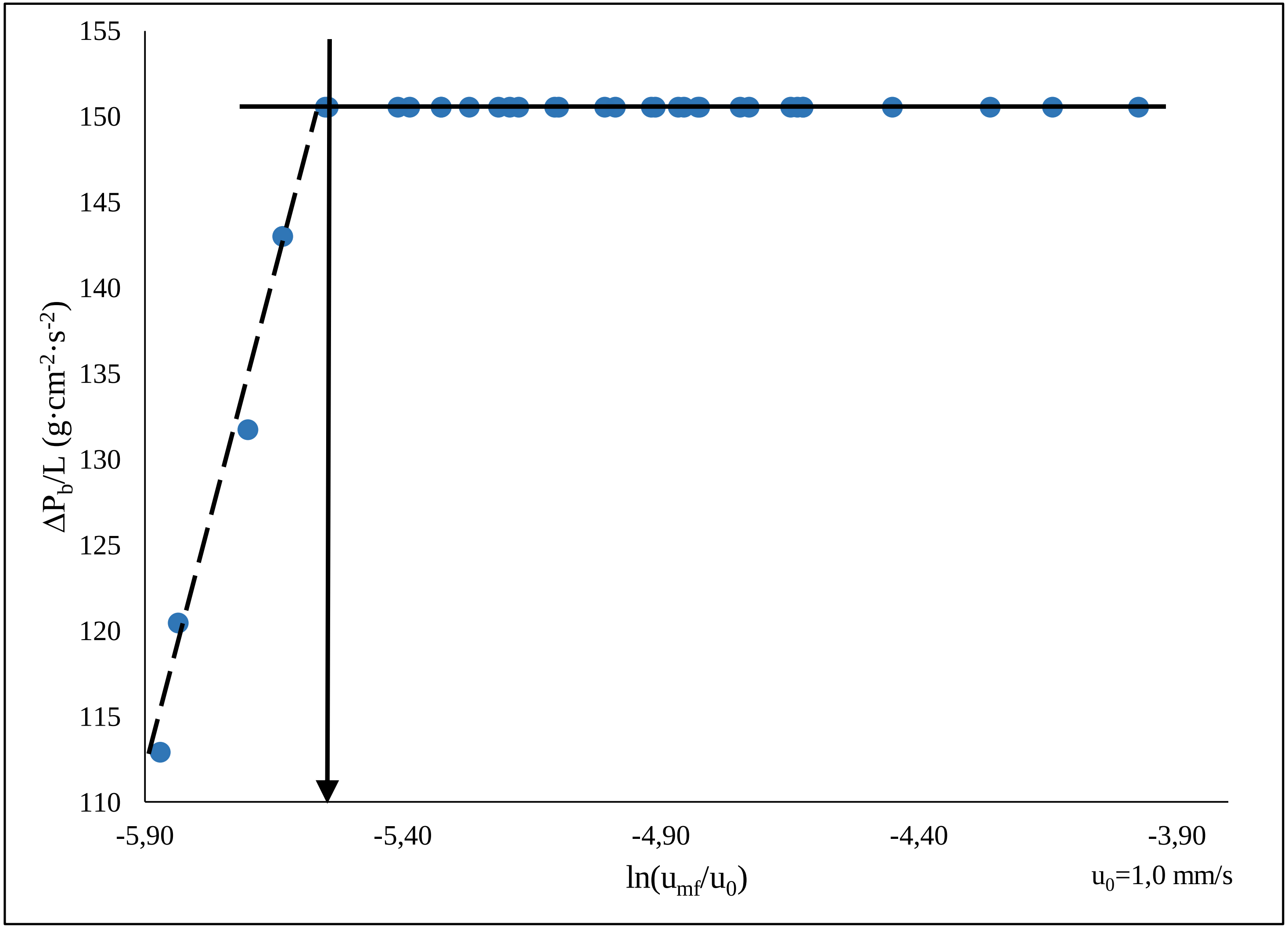


Figure 5. Variation of bed pressure-drop with superficial water velocity for M size class.

Minimum Fluidization Velocity: Comparision Results

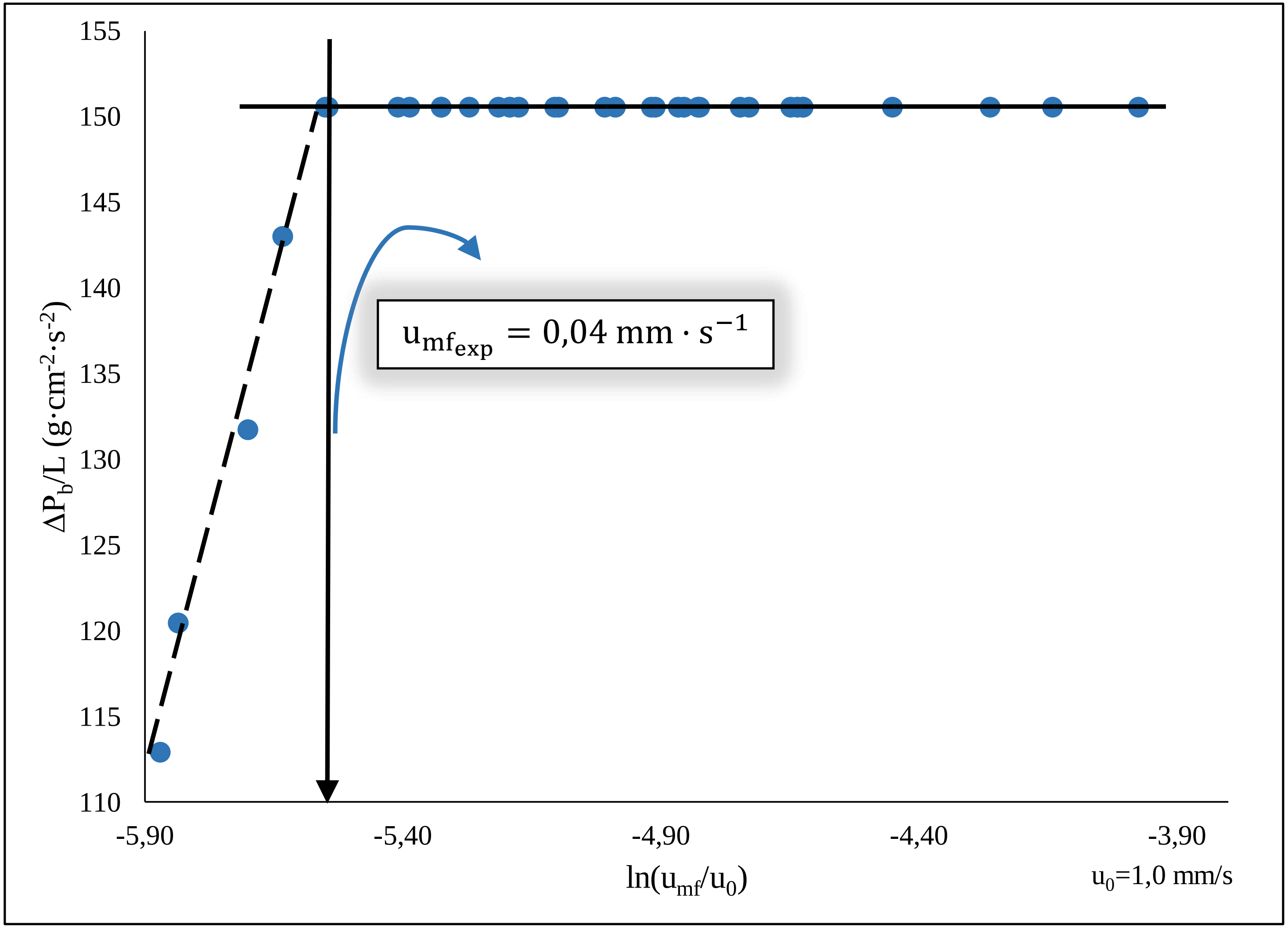


Size: S

m_b = 44 g
L_{mf} = 2,6 cm
ε_{mf} = 0,65

Figure 6. Variation of bed pressure-drop with superficial water velocity for S size class.

Minimum Fluidization Velocity: Comparision Results



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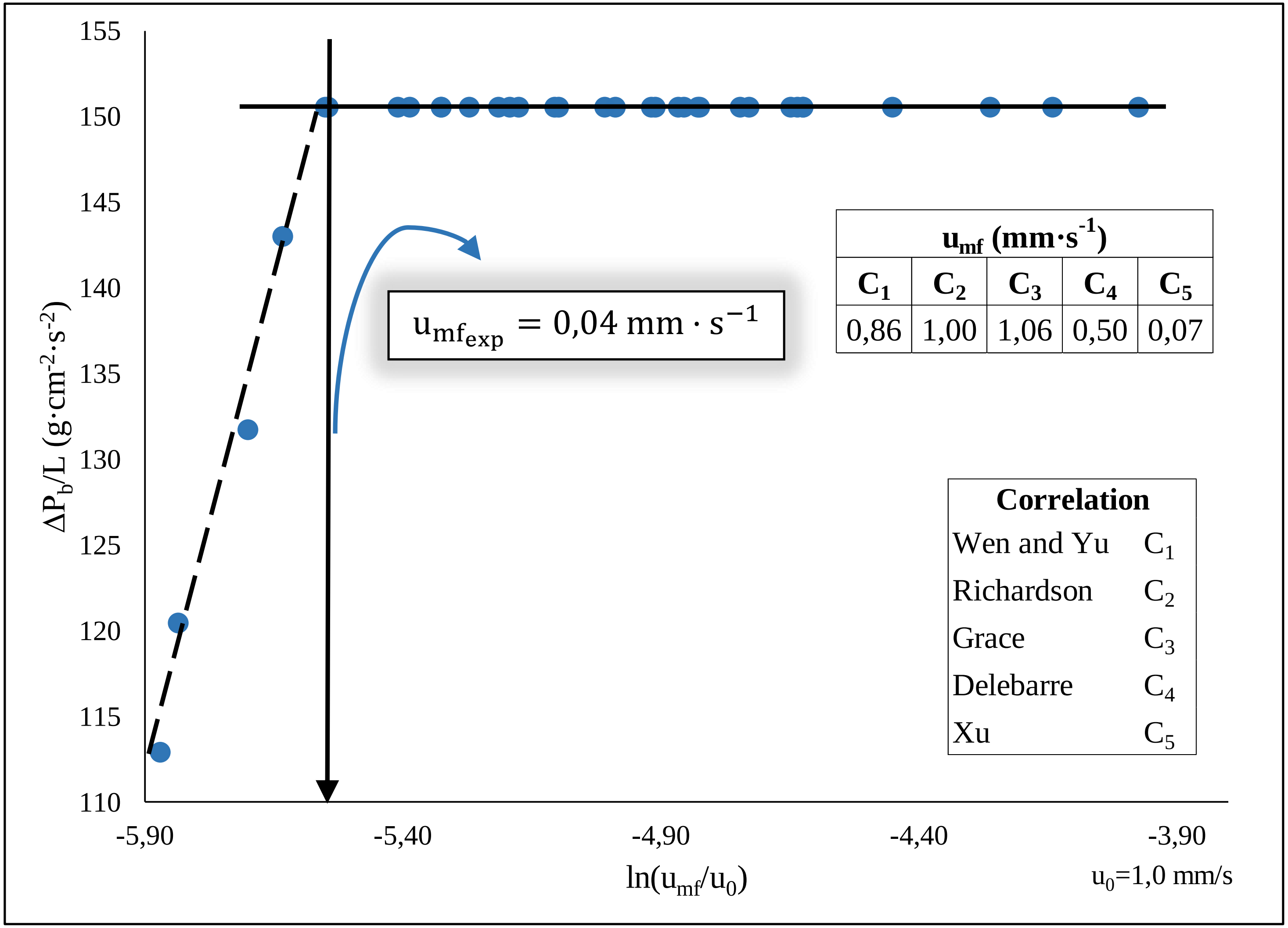

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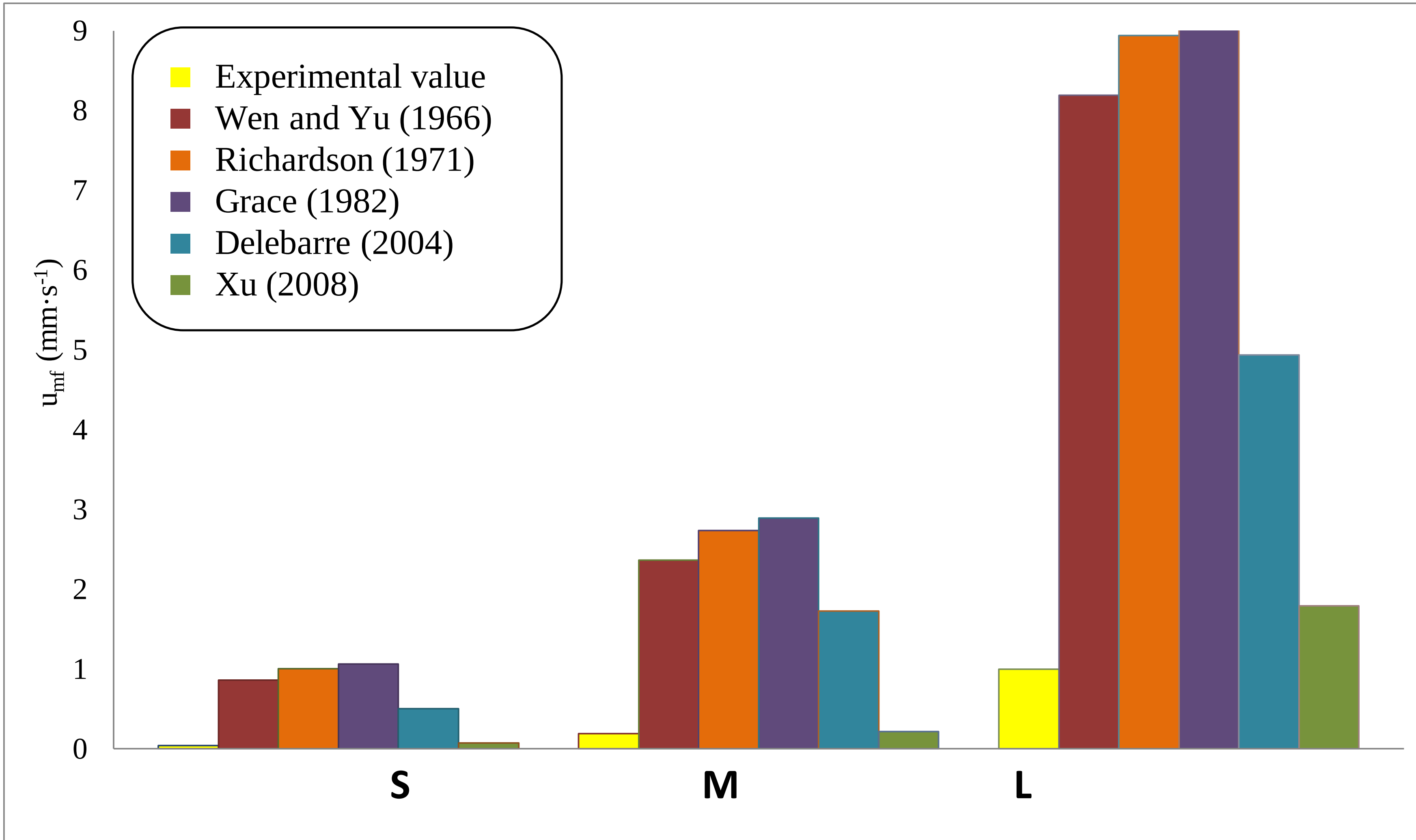
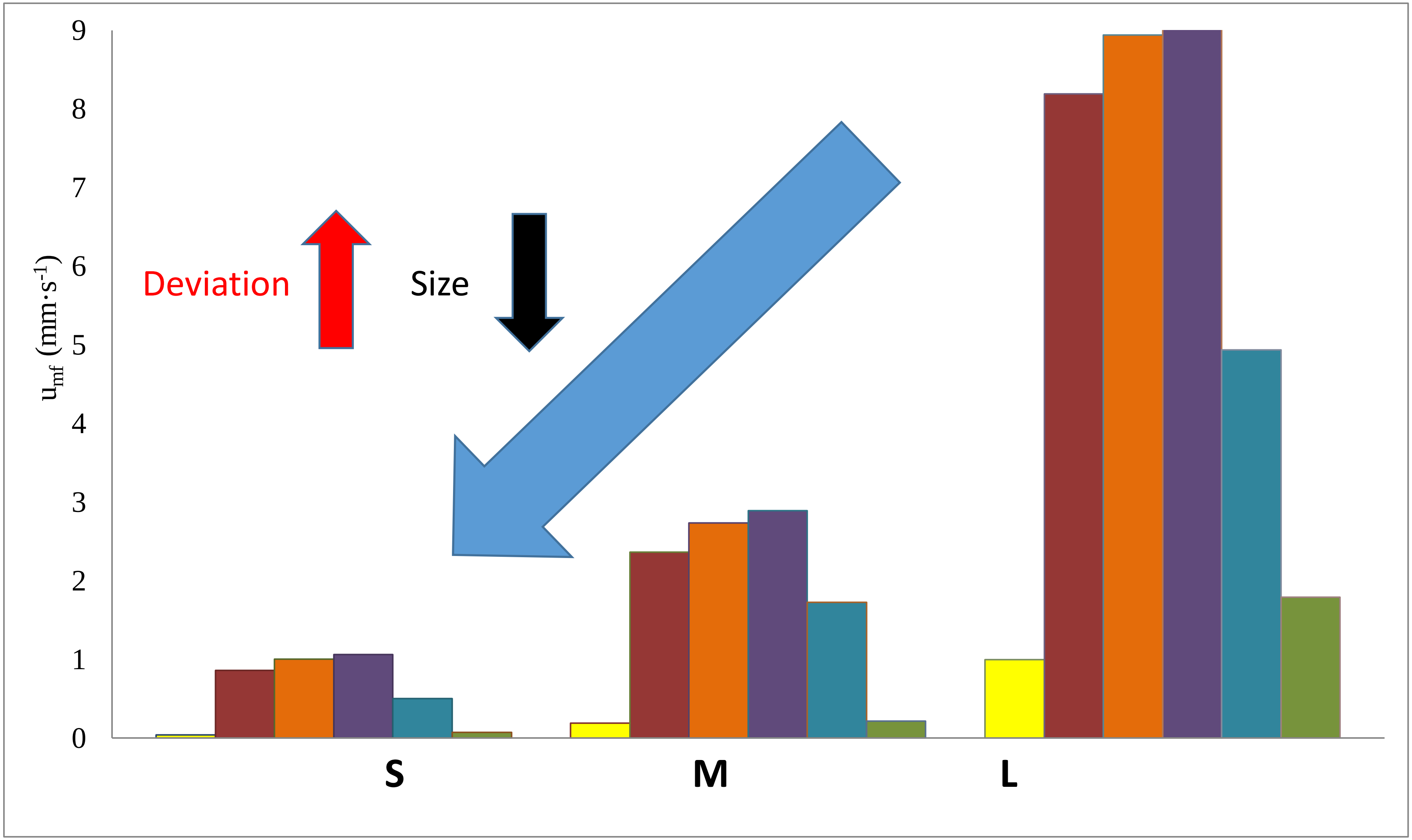
Minimum Fluidization Velocity: Comparision Results



Minimum Fluidization Velocity: Comparision Results



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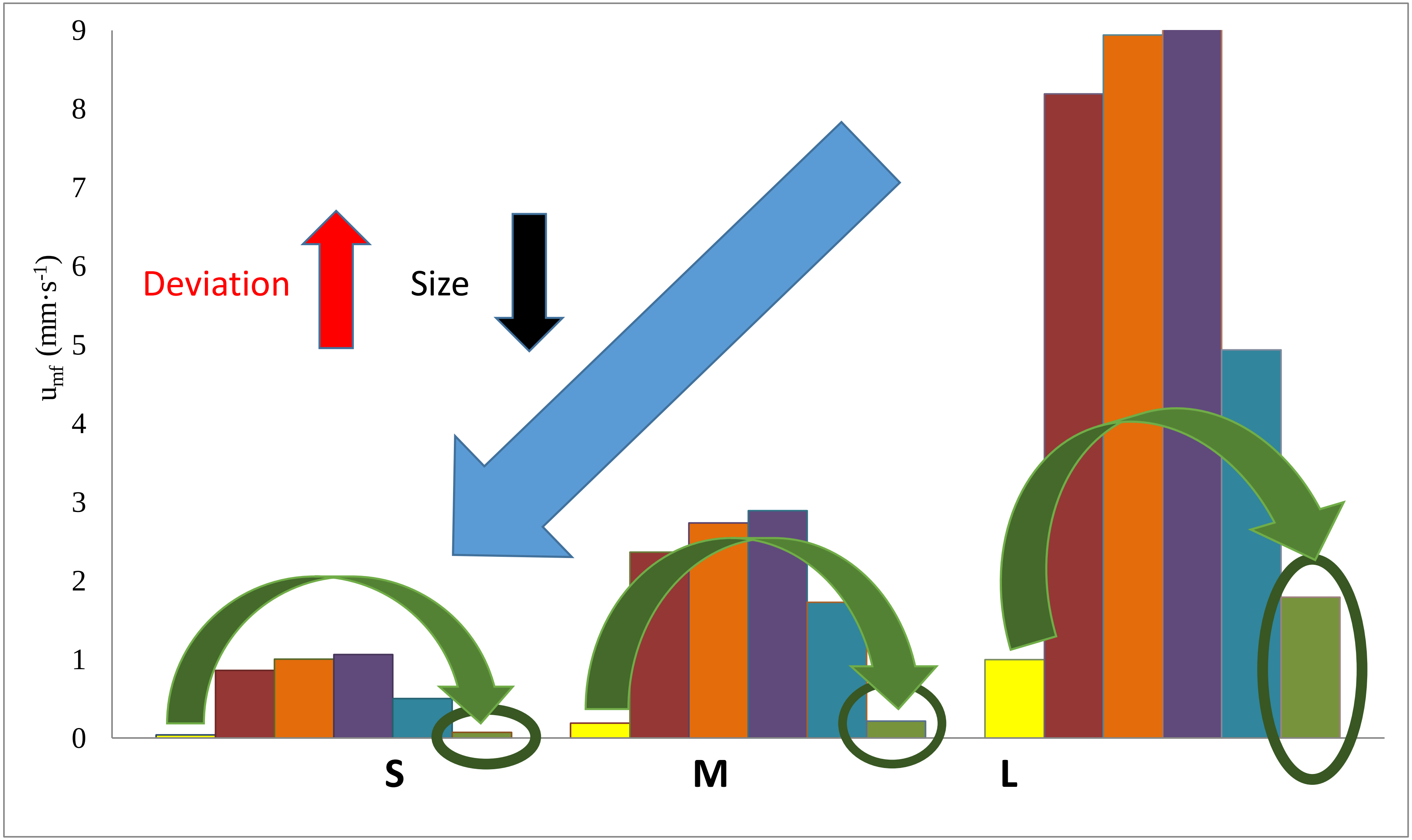

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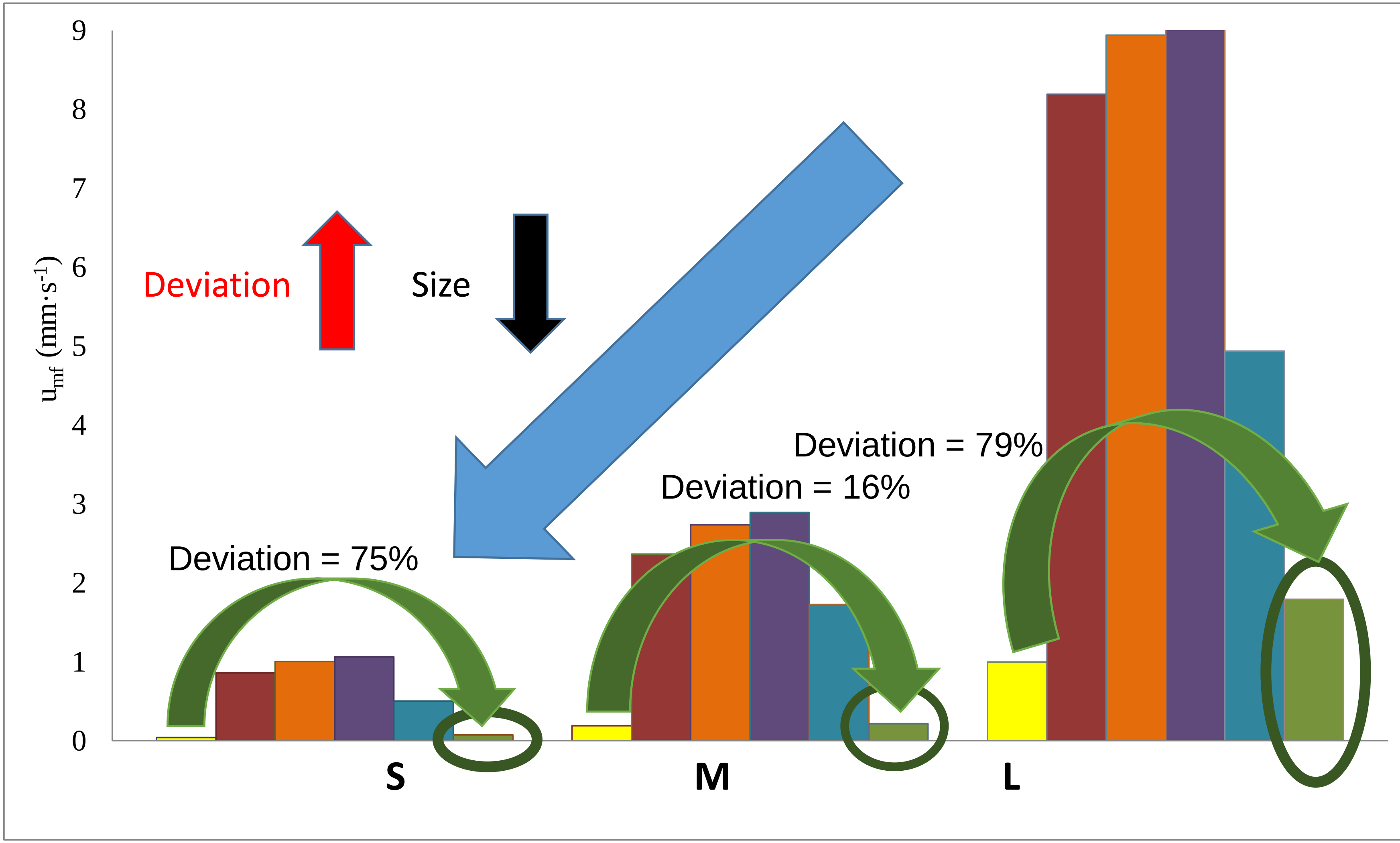

CONCLUSIONS

1. In all cases, the **evaluated correlations overestimate u_{mf}**.

2. For medium **particles M**, **with relative high degree of cohesiveness**, the u_{mf} can be predicted with **good accuracy** using **Xu's correlation**. For **smaller (S) and higher (L)** struvite particles, **this correlation** presents the **better approximation**.

3. The **predicted u_{mf}** using **Wen and Yu's**, **Richardson's** or **Grace's** equations, **deviates significantly from the experimental values** in all assayed sizes class, this **deviation increases as the particle size decreases**. **Delebarre's** correlation presents a **better prediction than** the commonly and **traditionally** used **equations**.

4. **Correlations** for the **prediction** of **minimum fluidization velocity** for **struvite** particles should be used as a **rough guide only**.

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Thanks!

¡Gracias!

Aguyje!