TURBIDITY CURRENTS PHYSICAL EXPERIMENTS AT THREE DIFFERENT SCALES: DATA PARAMETERIZATION THROUGH DIMENSIONAL ANALYSIS AND MULTIPLES REGRESSION MODELS

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CONTEXT

As research results show turbidity currents are very complex flow

Flow dynamics → Mechanims of deposition and erosion → Deposit distribution

Why parameterizate it?

To correlate and combine all approches used to study turbidity currents

Turbidite study & physical modeling & numerical simulation

Empirical and analytical laws

Field data

OBJECTIVES

OBJETIVO PRINCIPAL

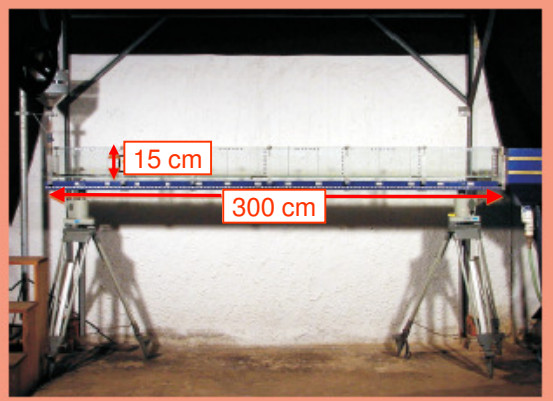
Consubstanciar os dados existentes, agrupando-os dentro de suas semelhanças e diferenças

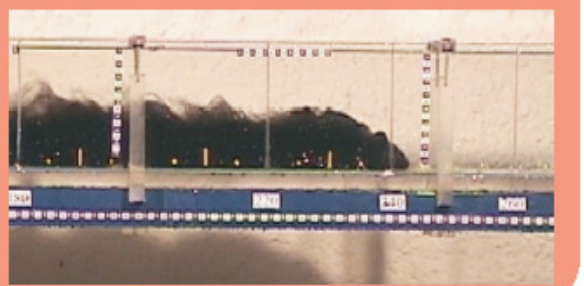
OBJETIVOS SECUNDÁRIOS

- Identificar pontos de convergência e tendências apresentadas
- Identificar situações, parâmetros e ferramentas que melhor apresentaram condições de similaridade
- Estabelecer “diretrizes” para a execução de novos ensaios, visando estender e complementar as séries de dados já existentes.

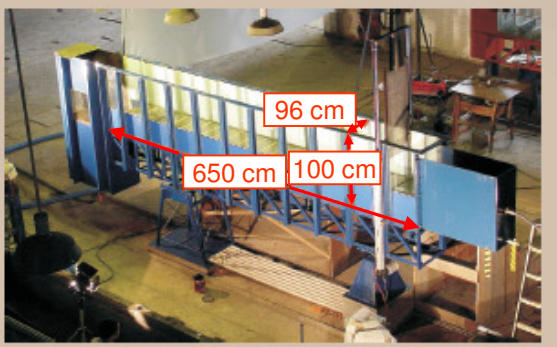
SIMULATIONS WITH DIFFERENT SETUPS

SMALL UNIDIRECTIONAL TANK (SUT)

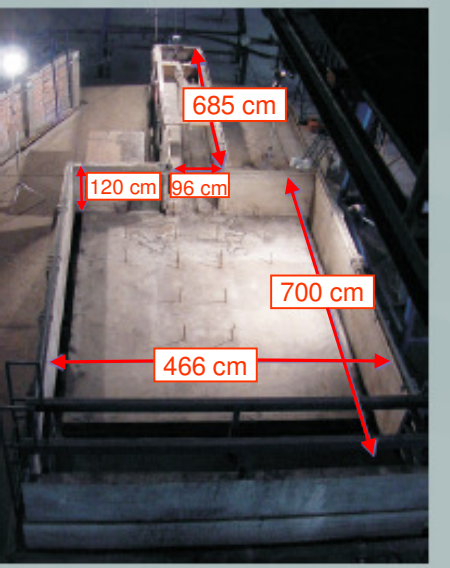




LONG UNIDIRECTIONAL TANK (LUT)



SIMPLIFIED TRIDIMENSIONAL TANK (STT)



DATA MEASUREMENT

Inlet parameters

d_m = grain size [m]

ω_s = fall velocity [m.s]

ρ_s = sediment density [kg.m^{-3}]

ρ_m = mixture density [kg.m^{-3}]

g' = reduced gravity [m.s^{-2}]

ν_m = mixture kinematic viscosity [m^2.s]

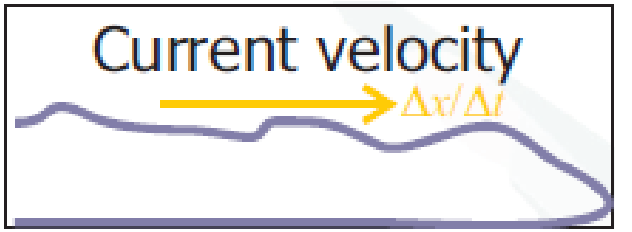
μ_m = mixture dynamic viscosity [Ns.m^2]

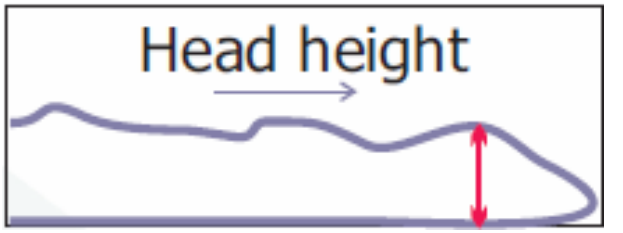
C_v = volumetric concentration [1]

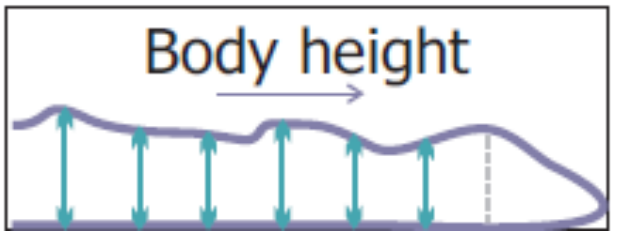
V_m = mixture volume [m^3]

Q = flow rate [m^3.s]

q = linear flow rate [m^2.s]







		Dücker *et al.* (2002)	Manica *et al.* (2005)	Puhl *et al.* (2004)	Giacomel *et al.* (2003)	Giacomel *et al.* (2005)	Fabian (2002)	Brito (2005)	Del Rey (2005)	Manica (2002)
	Number of experiments	5	14	5	22	26	12	17	12	9
	Physical model	SUT	SUT	SUT	SUT	SUT	LUT	LUT	STT	STT
	Ignition type	Continuous flux	Continuous flux and Lock-box	Continuous flux	Continuous flux	Continuous flux	Lock-box	Continuous flux	Continuous flux	Continuous flux
	Slope [°]	0°	0°	0°	0°	0°	-0.5° – 4.0°	-0.5° – 2.0°	Varied	Varied
	Mixture sediment	Salt (d=2.2) and/or Coal (d=1.365)	Coal (d=1.36/1.19) Calcareous (d=2.832)	Coal (d=1.365)	Coal (d=1.36/1.19)	Coal (d=1.19)	Salt (d=2.2)	Coal (d=1.36/1.19)	Coal (d=1.19)	Coal (d=1.19)
d_m	Grain Size [10^{-6} m]	115 (Coal)	125 (d=1.365) 60-113 (d=1.19) 45-56 (d=2.832)	125-139	42 (d=1.365) 40-95 (d=1.19)	95	---	104-124 (d=1.36) 53-105 (d=1.19)	72-109	73-110
ω_s	Fall velocity [10^{-3} m/s]	1.9	3 (d=1.365) 0.4-1.3 (d=1.19) 1.9-3.1 (d=2.832)	3-3.8	0.3 (d=1.365) 0.1-0.9 (d=1.19)	0.9	---	2.1-3 (d=1.365) 0.3-1.1 (d=1.19)	0.5-1.2	0.5–1.2
C_v	Volumetric concentration [%]	0.78 - 3.39	1.24 - 12.30	10.48	6.38 - 14.50	4.56 - 14.39	1.08 - 2.07	3.31 - 19.37	24x 18.93	6.59 - 13.45
μ_m	Dynamic viscosity [10^{-3} Ns/m²]	1.02 – 1.094	1.031 – 1.412	1.344	1.191 – 1.500	1.130 – 1.495	1.027 – 1.055	1.091 – 1.713	1.111 – 1.693	1.198 – 1.457
g'	Reduced gravity [m/s²]	0.122 - 0.127	0.118 - 0.239	0.379	0.217 - 0.275	0.086 - 0.273	0.127 - 0.245	0.119 - 0.367	0.075 - 0.359	0.125 - 0.255
V_m	Mixture volume [10^{-3} m³]	4.00 - 4.15	4.04 - 4.57	4.00 - 4.47	4.00	4.00	71.30 - 117.70	50.00	50.00 - 480.00	24x 00
Q	Flow rate [10^{-6} m³/s]	82.4 - 118.5	95.7 - 277.1	68.6 - 139.7	87.7 - 216.6	86.9 - 129.0	1073.6 - 2844.5	41x 75.0	83.3 - 600.0	166.6 - 583.3
U	Current velocity [m/s]	0.029 - 0.045	0.014 - 0.081	0.028 - 0.067	0.005 - 0.103	0.039 - 0.058	0.071 - 0.118	24x 0.090	0.019 - 0.107	0.052 - 0.086
h_{head}	Head height [m]	0.052 - 0.073	0.051 - 0.061	0.033 - 0.052	---	0.025 - 0.053	0.062 - 0.080	0.050 - 0.137	5x ---	---
h_{body}	Body height [m]	0.065 - 0.098	0.042 - 0.071	0.031 - 0.053	---	0.034 - 0.072	0.025 - 0.034	0.073 - 0.223	9x ---	---

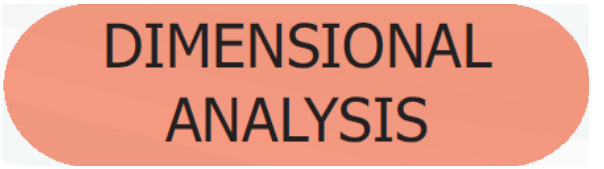
		Dücker *et al.* (2002)	Manica *et al.* (2005)	Puhl *et al.* (2004)	Giacomel *et al.* (2003)	Giacomel *et al.* (2005)	Fabian (2002)	Brito (2005)	Del Rey (2005)	Manica (2002)
	Number of experiments	5	14	5	22	26	12	17	12	9
	Physical model	SUT	SUT	SUT	SUT	SUT	LUT	LUT	STT	STT
					Altinakar (1988)		Michon et al. (1955)		Garcia (1985)	
	Number of experiments				17		21		15	
	Physical Model [m]				16.50 x 0.50 x 0.80		21.00 x 0.80 x 0.47		25.00 x 0.70 x 1.80	
	Ignition type				Continuous flow		Continuous flow		Continuous flow	
	Slope [°]				0° - 2.07°		0.34° - 2.06°		2.87° - 4.57°	
d_m	Mixture sediment				Quartz (d=2.65)		Caulim (d=2.15 and d=2.45)		Silic (d=2.65)	
ω_s	Grain size [10^{-6} m]				26 and 46.7		15		30 – 60	
	Fall velocity [10^{-3} m/s]				0.61 and 1.96		0.011 – 0.31		0.5 – 4.4	
C_v	Volumetric concentration [%]				0.15 - 0.45		0.09 - 0.58		0.3 - 0.83	
μ_m	Dinamic viscosity [10^{-3} Ns/m^2]				1.004 – 1.011		1.002 – 1.014		1.008 – 1.021	
g'	Reduced gravity [m/s^2]				0.018 - 0.055		0.012 - 0.082		0.049 - 0.134	
V_m	Flow rate [10^{-6} m^3/s]				1300.0 - 4850.0		3000.0 – 20000.0		10500.0 – 25000.0	
Q	Current velocity [m/s]				0.03 - 0.068		0.042 - 0.128		0.116 - 0.189	
U	Head height [m]				0.128 - 0.300		0.064 - 0.22		0.19 - 0.26	
	Body height [m]				Not obtained		Not obtained		Not obtained	
	[m/s]									
h_{head}	Head height [m]	0.052 - 0.073	0.051 - 0.061	0.033 - 0.052	---	0.025 - 0.053	0.062 - 0.080	0.050 - 0.137	---	---
h_{body}	Body height [m]	0.065 - 0.098	0.042 - 0.071	0.031 - 0.053	---	0.034 - 0.072	0.025 - 0.034	0.073 - 0.223	---	---

5x

9x

DATA ANALYSIS

DIMENSIONAL ANALYSIS



$$f(W^*, h^*, U, Q, g', \rho_m, \mu_m, \rho_s, \omega_s) = 0$$

Diverse non-dimensional

$$\mathrm{Re}_{head} = \frac{U h_{head}}{\nu_m} \quad \mathrm{Ri}_{head} = \frac{g' h_{head}}{U^2} \quad \mathrm{Ri}_{body} = \frac{g' h_{body}}{U^2} \quad \mathrm{Re}_{grain} = \frac{U d_m}{\nu_m}$$

$$\mathrm{Ar}_{body} = \frac{h_{body}^3 g'}{\nu_m^2} \quad \mathrm{Ar}_{head} = \frac{h_{head}^3 g'}{\nu_m^2} \quad \mathrm{Re}_{body} = \frac{U h_{body}}{\nu_m} \quad \mathrm{Ke} = \frac{U^3}{\nu_m g'}$$

and others...

REGRESSION MODELS

Monomial Power-law models

Dependent parameters $= f($ Independent parameters $)$

$$y = x_1^a x_2^b x_3^c$$

DIMENSIONAL ANALYSIS

1st step:

List the most significant flow parameters

- Characteristic current dimension (W^*)
- Characteristic current height (h^*)
- Current velocity (U)
- Flow rate (Q)
- Reduced gravity (g')
- Mixture density (ρ_m)
- Dynamic viscosity (μ_m)
- Sediment density (ρ_m)
- Fall velocity (ω_s)

2nd step:

Base relation from 1st step

$$f(W^*, h^*, U, Q, g', \rho_m, \mu_m, \rho_s, \omega_s) = 0$$

DIMENSIONAL ANALYSIS

3rd step:

Dimensional relations resulting diverse non-dimensional groups

$$\Pi_1 = \frac{Q}{UWh_{head}} \qquad \Pi_2 = \frac{Q}{UWh_{body}} \qquad \Pi_3 = \mathrm{Re}_{grain} = \frac{Ud_m}{\nu_m}$$

$$\Pi_4 = \mathrm{Re}_{head} = \frac{Uh_{head}}{\nu_m} \qquad \Pi_5 = \mathrm{Re}_{body} = \frac{Uh_{body}}{\nu_m} \qquad \Pi_6 = \mathrm{Ri}_{head} = \frac{g' h_{head}}{U^2}$$

$$\Pi_7 = \mathrm{Ri}_{body} = \frac{g' h_{body}}{U^2} \qquad \Pi_8 = \frac{\omega_s}{U} \qquad \Pi_9 = \frac{h_{head} g'^{1/5}}{Q^{2/5}}$$

$$\Pi_{10} = \frac{h_{body} g'^{1/5}}{Q^{2/5}} \qquad \Pi_{11} = \frac{\rho_s}{\rho_m} \qquad \Pi_{12} = \frac{(\rho_s - \rho_m)}{\rho_m}$$

$$\Pi_{13} = \frac{W}{h_{head}} \qquad \Pi_{14} = \frac{W}{h_{body}} \qquad \Pi_{15} = \frac{Qg'^{1/3}}{\nu_m^{5/3}}$$

$$\Pi_{16} = \mathrm{Ar}_{head} = \frac{h_{head}^3 g'}{\nu_m^2} \qquad \Pi_{17} = \mathrm{Ar}_{body} = \frac{h_{body}^3 g'}{\nu_m^2} \qquad \Pi_{18} = \mathrm{Ke} = \frac{U^3}{\nu_m g'}$$

$$\Pi_{19} = \mathrm{St}_{head} = \frac{U\nu_m}{h_{head}^2 g'} \qquad \Pi_{20} = \mathrm{St}_{body} = \frac{U\nu_m}{h_{body}^2 g'} \qquad \Pi_{21} = \mathrm{Fr}'_{head} = \frac{U}{\sqrt{g' h_{head}}}$$

$$\Pi_{22} = \mathrm{Fr}'_{body} = \frac{U}{\sqrt{g' h_{body}}}$$

DIMENSIONAL ANALYSIS

3rd step:

Dimensional relations resulting diverse non-dimensional groups

$$\Pi_1 = \frac{Q}{UWh_{he}}$$

$$\Pi_4 = \mathrm{Re}_{head}$$

$$\Pi_7 = \mathrm{Ri}_{body}$$

$$\Pi_{10} = \frac{h_{body}g}{Q^2}$$

$$\Pi_{13} = \frac{W}{h_{head}}$$

$$\Pi_{16} = \mathrm{Ar}_{head}$$

$$\Pi_{19} = \mathrm{St}_{head}$$

$$\Pi_{22} = \mathrm{Fr}'_{body} = \frac{}{\sqrt{g'h_{body}}}$$

4th step:

New groups from algebric operations between the old ones

$$\Pi_{23} = \frac{\Pi_8}{\Pi_6} = \frac{U\omega_s}{g'h_{head}}$$

$$\Pi_{24} = \frac{\Pi_8}{\Pi_7} = \frac{U\omega_s}{g'h_{body}}$$

$$\Pi_{25} = \Pi_{18} \times \Pi_{13} = \frac{U^3W}{\nu_m g'h_{head}}$$

$$\Pi_{26} = \Pi_{18} \times \Pi_{14} = \frac{U^3W}{\nu_m g'h_{body}}$$

$$\Pi_{27} = \Pi_{18} \times \Pi_8 = \frac{U^2\omega_s}{\nu_m g'}$$

$$\Pi_{28} = \frac{\Pi_{15}}{\Pi_1} = \frac{UWh_{head}g'^{1/3}}{\nu_m^{5/3}}$$

$$\Pi_{29} = \frac{\Pi_{15}}{\Pi_2} = \frac{UWh_{body}g'^{1/3}}{\nu_m^{5/3}}$$

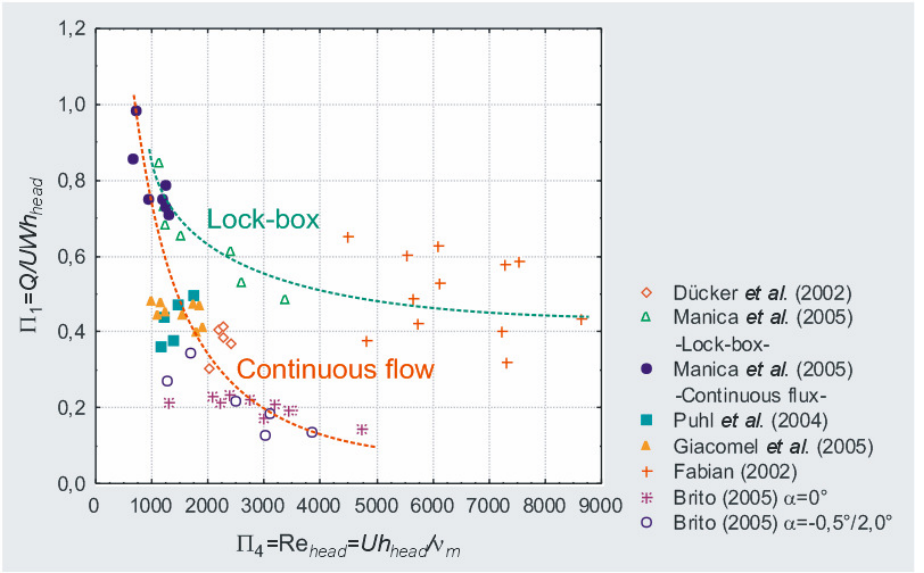
$$\Pi_{30} = \Pi_9 \times \Pi_{13} = \frac{Wg'^{1/5}}{Q^{2/5}}$$

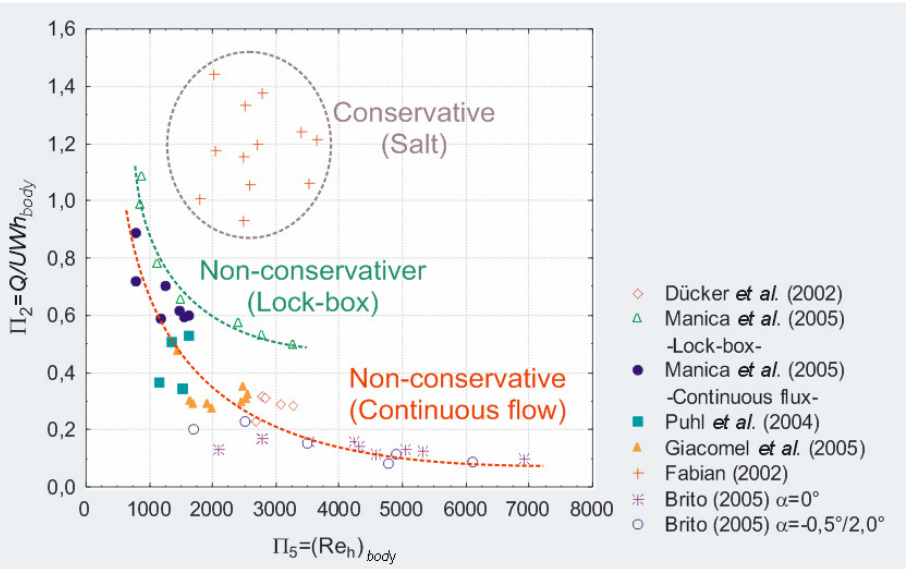
$$\Pi_{31} = \Pi_1 \times \Pi_{11} = \frac{Q\rho_s}{UWh_{head}\rho_m}$$

$$\Pi_{32} = \Pi_1 \times \Pi_{12} = \frac{Q(\rho_s - \rho_m)}{UWh_{head}\rho_m}$$

DIMENSIONAL ANALYSIS

CURRENTS DYNAMICS





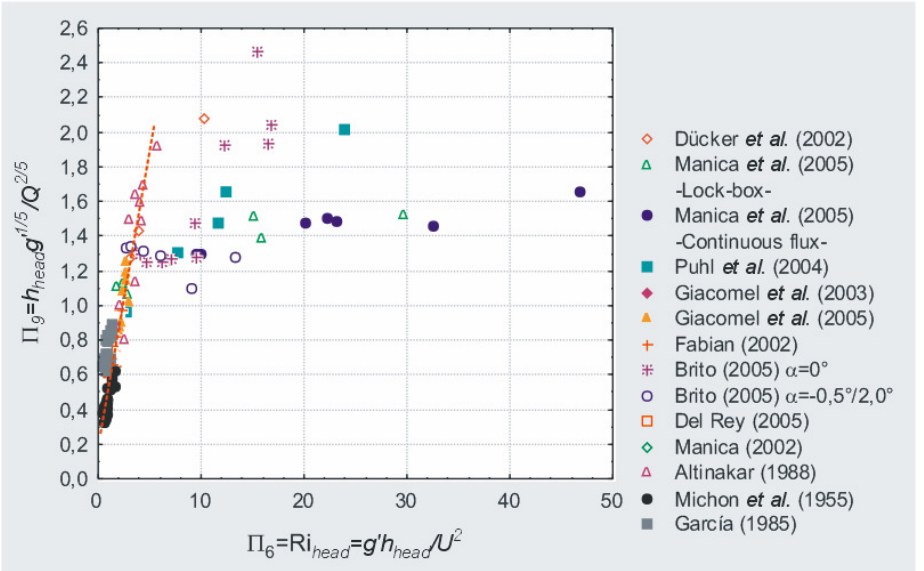
LOCK-BOX vs. CONTINUOUS FLOW:

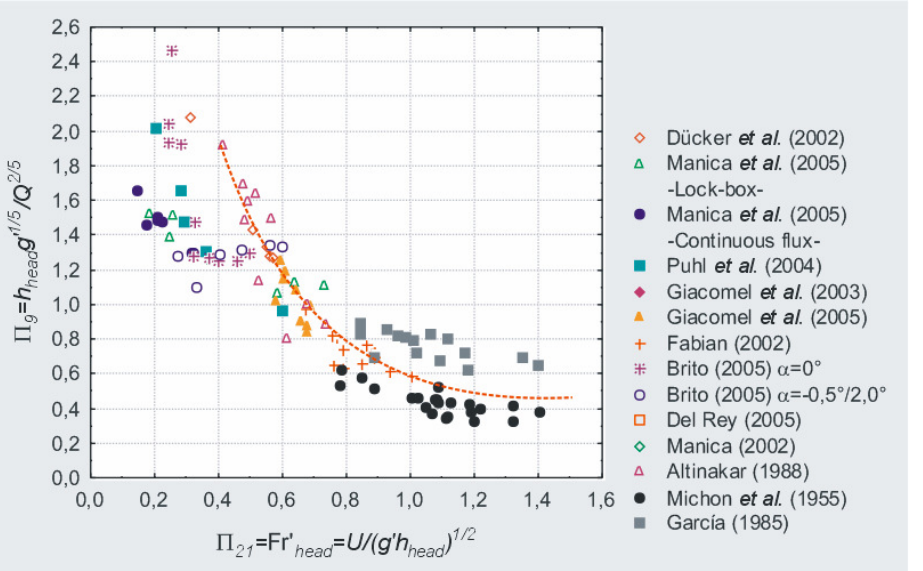
Different hydrodinamics = Different trends

Lock-box cannot be approximated by continuous flow

DIMENSIONAL ANALYSIS

CURRENTS DYNAMICS



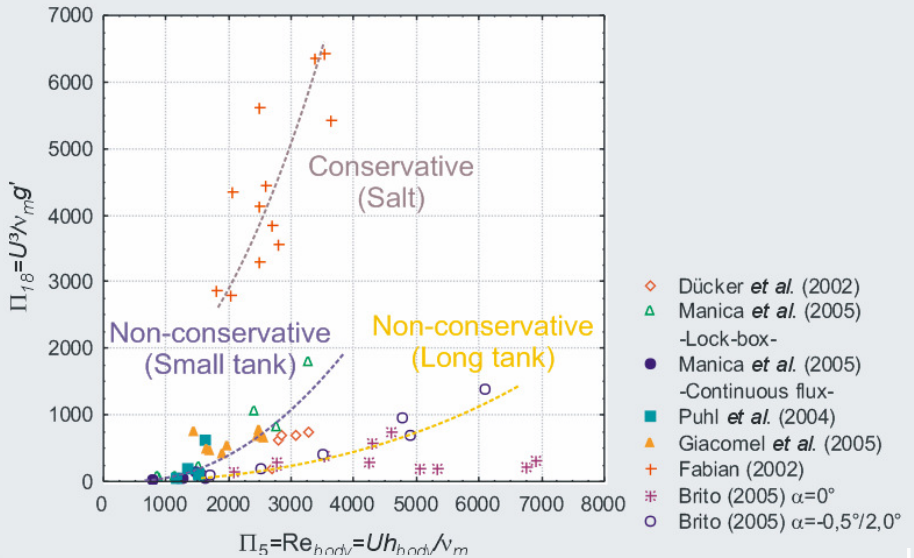


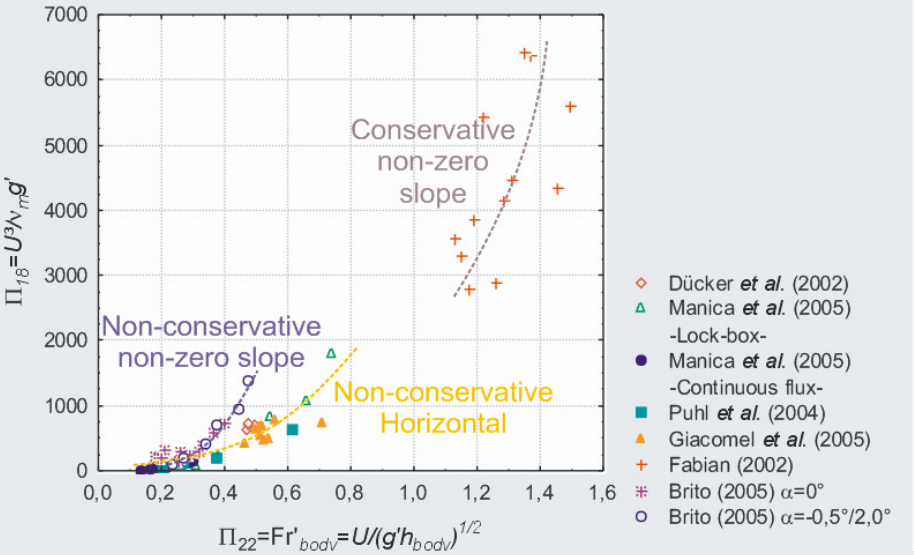
FLOW HOMOGENEITY:

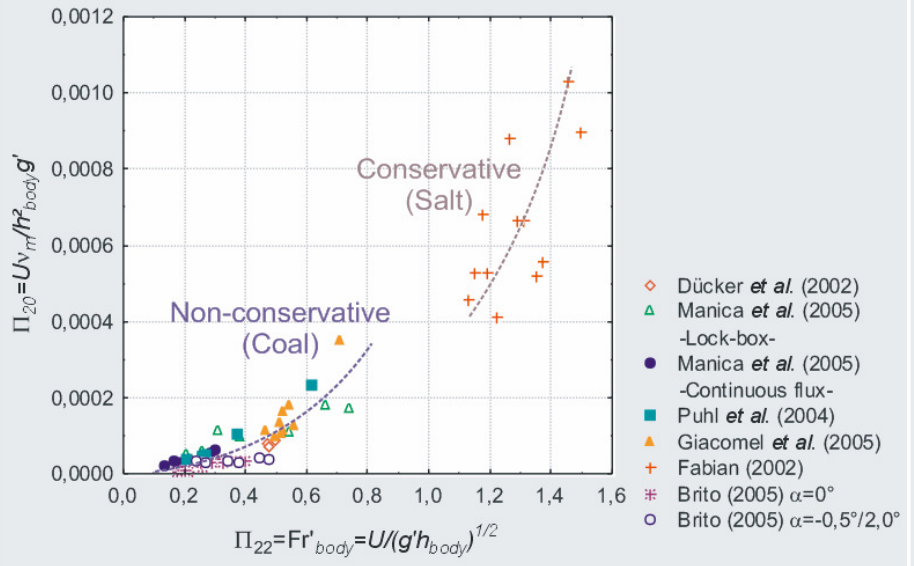
Concentration maintenance capacity of the flow and can be measured by the densimetric Froude

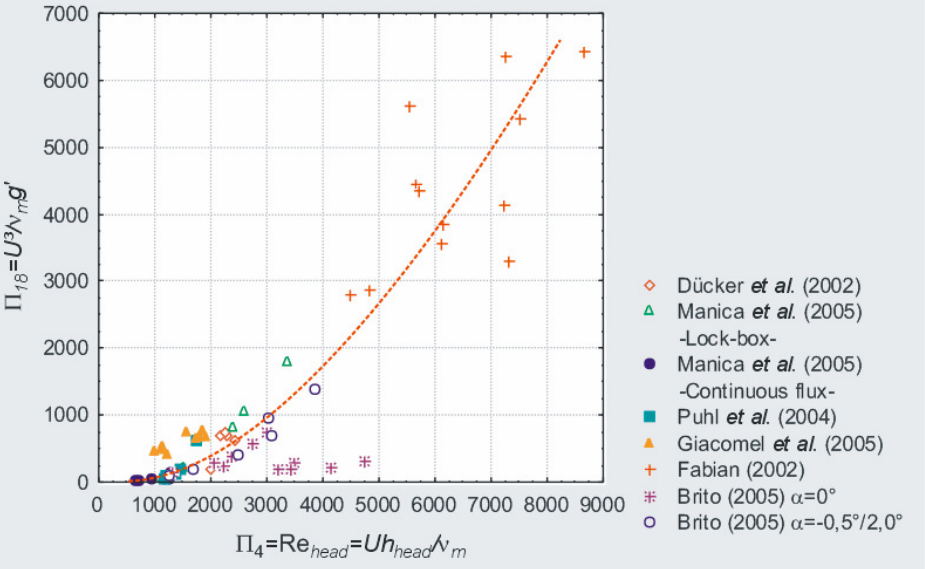
DIMENSIONAL ANALYSIS

CURRENTS DYNAMICS



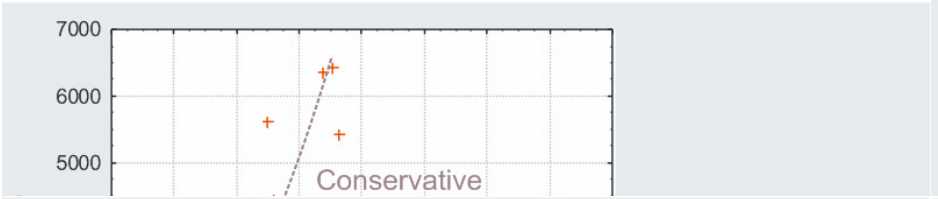


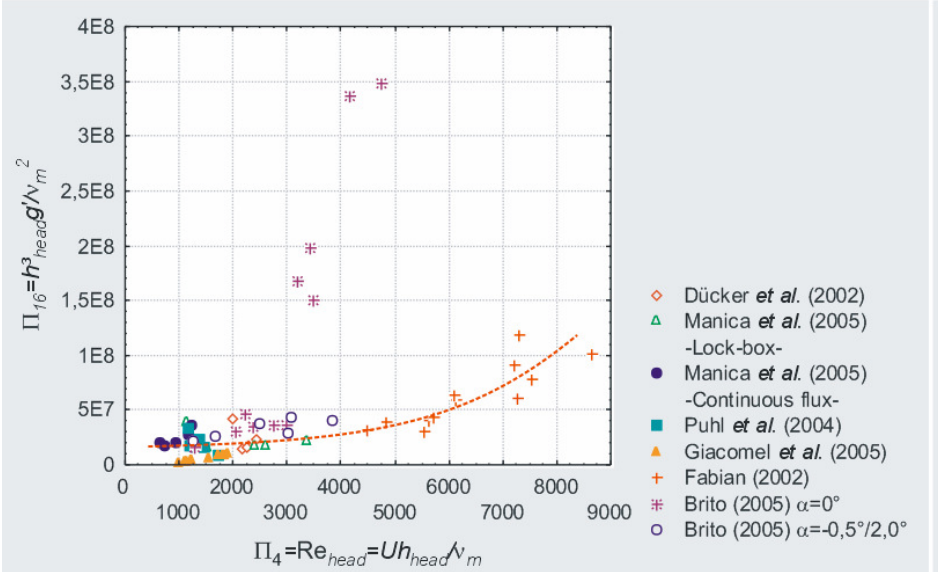


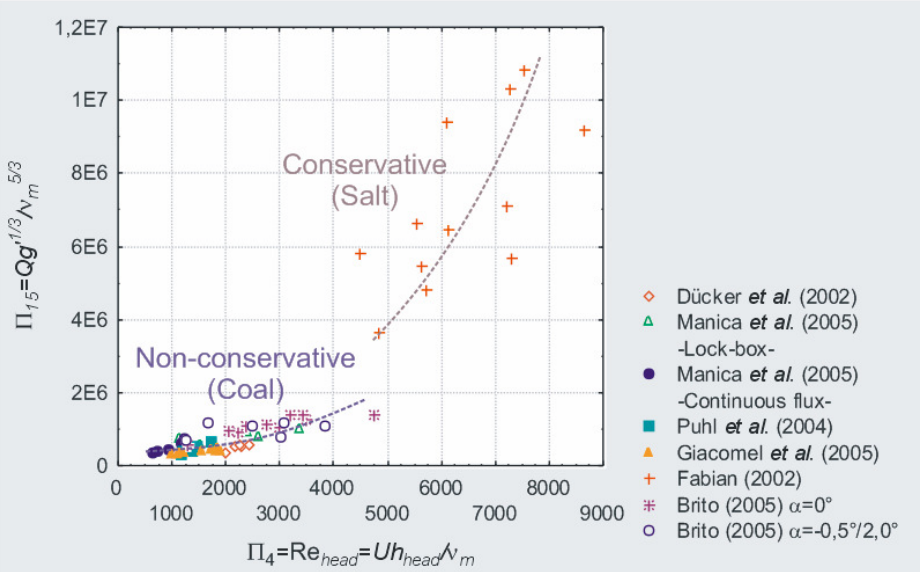


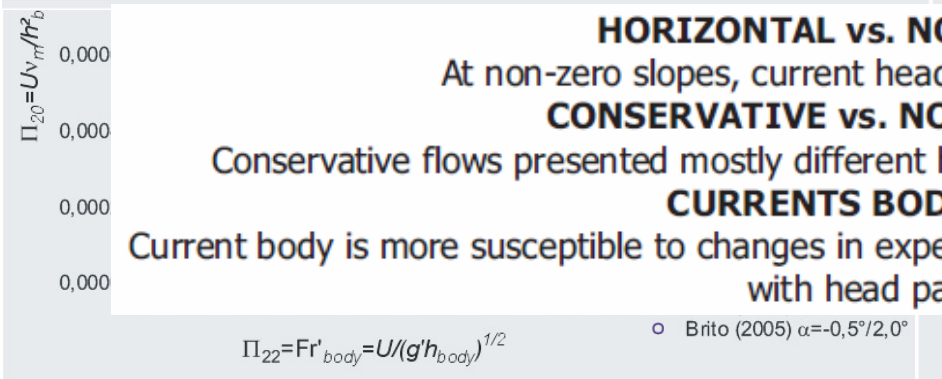
DIMENSIONAL ANALYSIS

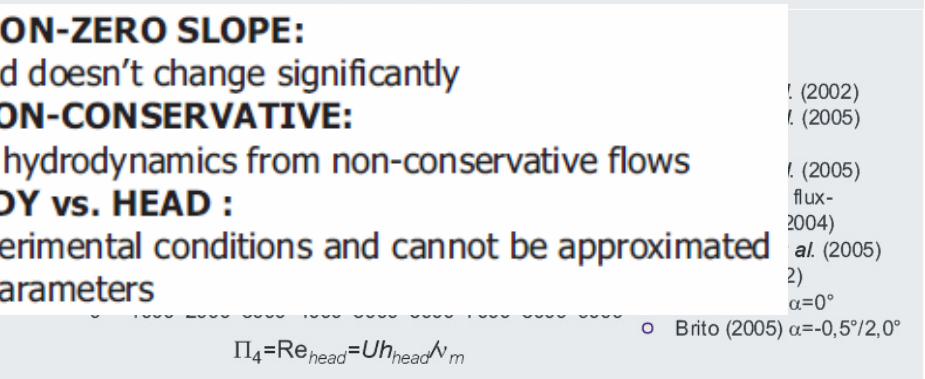
CURRENTS DYNAMICS











HORIZONTAL vs. NON-ZERO SLOPE:

At non-zero slopes, current head doesn't change significantly

CONSERVATIVE vs. NON-CONSERVATIVE:

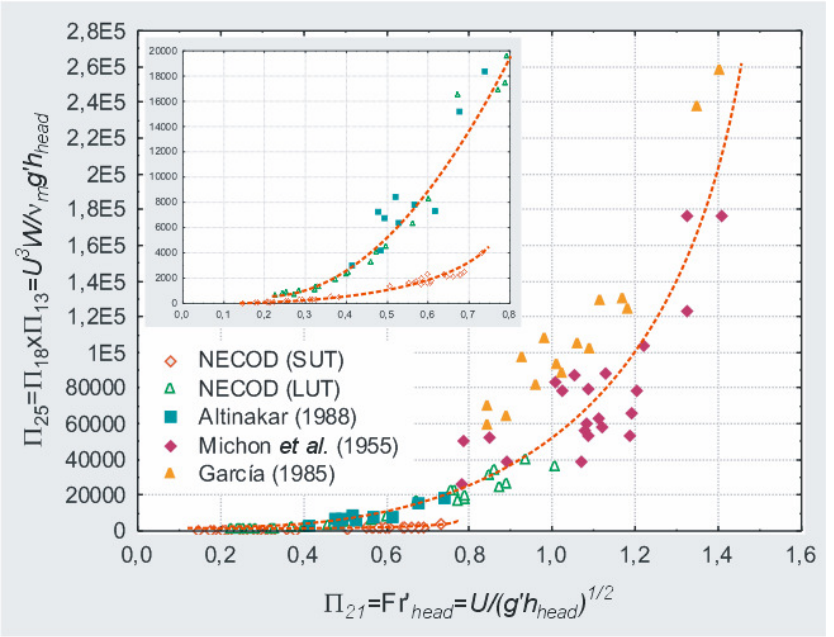
Conservative flows presented mostly different hydrodynamics from non-conservative flows

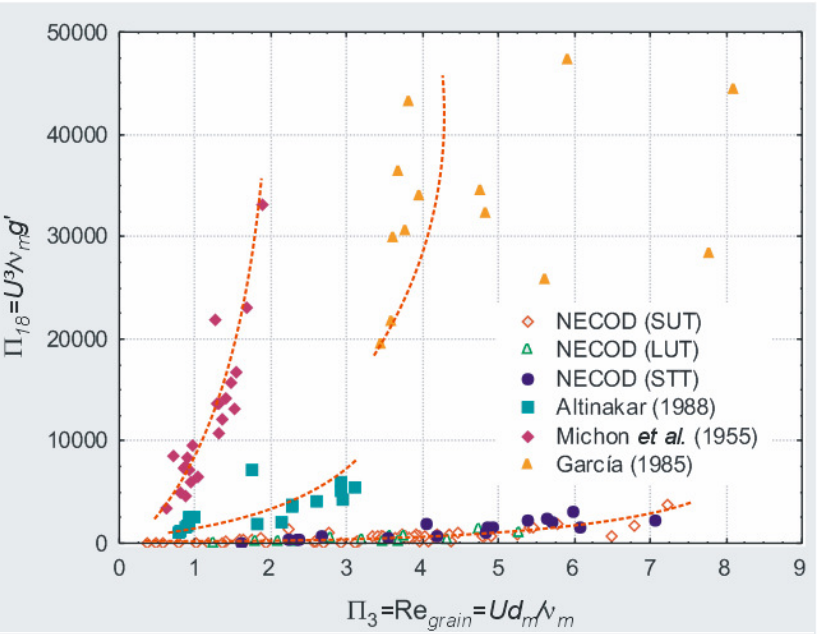
CURRENTS BODY vs. HEAD :

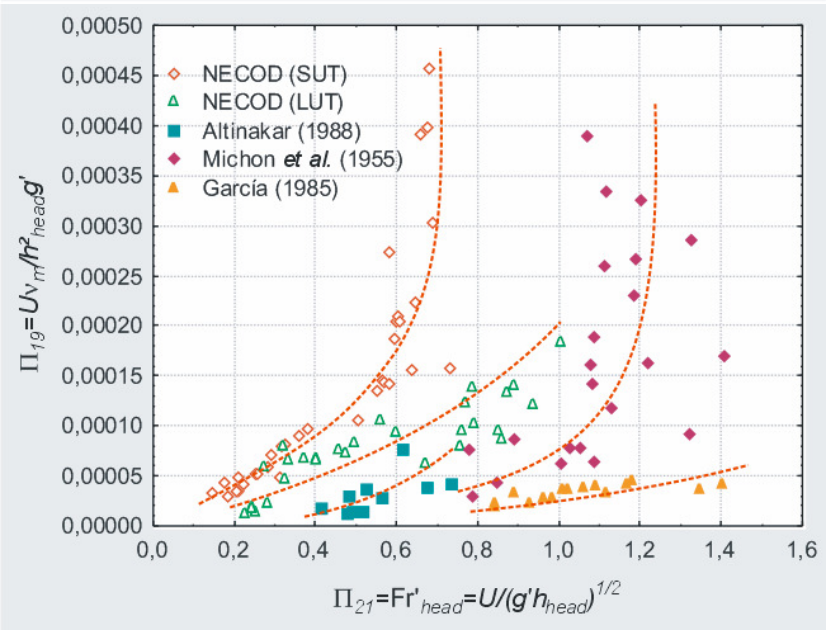
Current body is more susceptible to changes in experimental conditions and cannot be approximated with head parameters

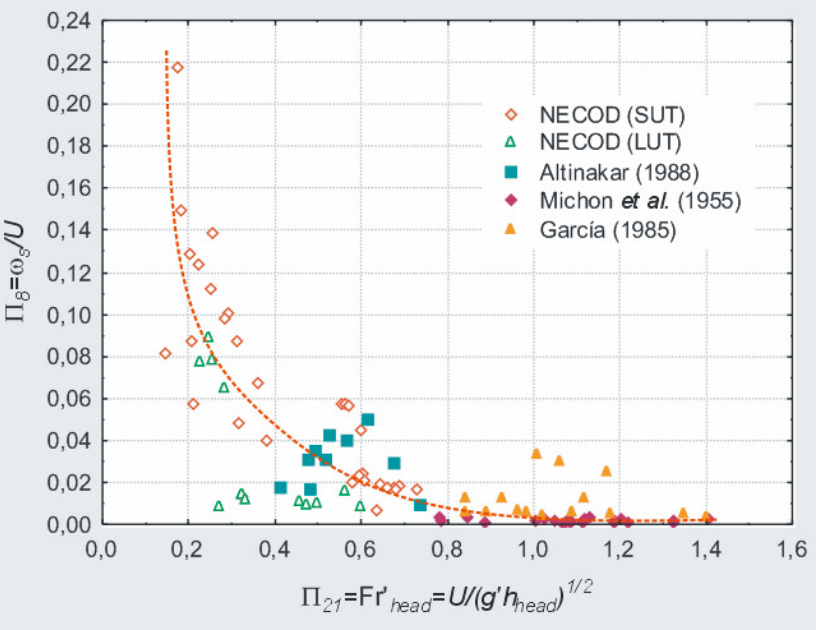
DIMENSIONAL ANALYSIS

PHYSICAL MODELS



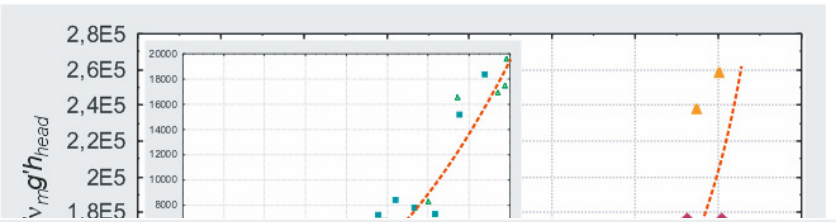


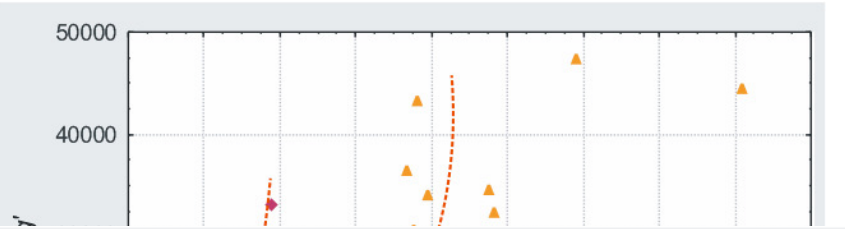


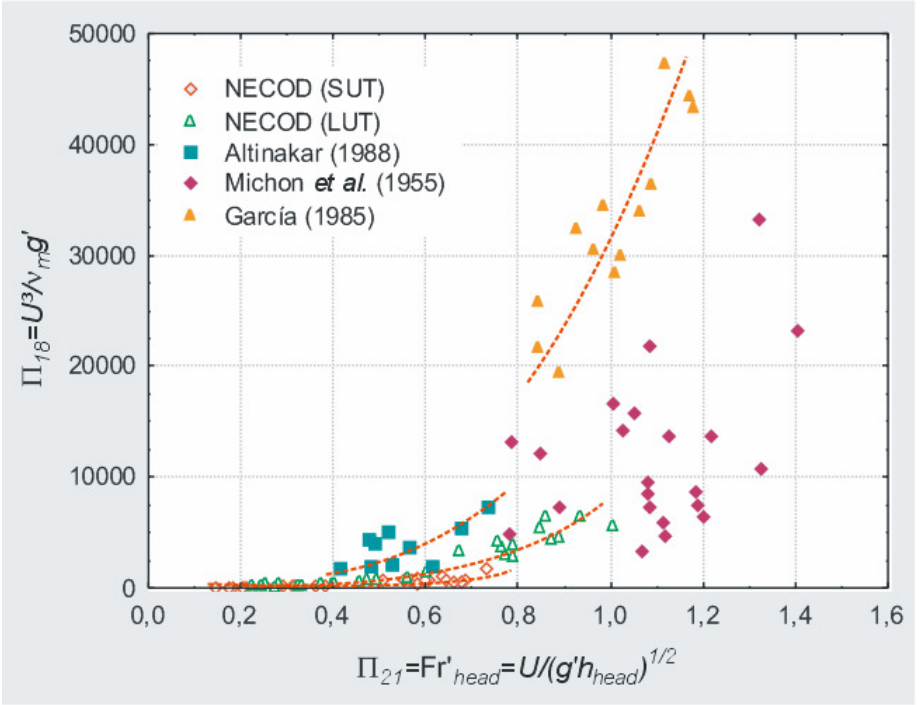


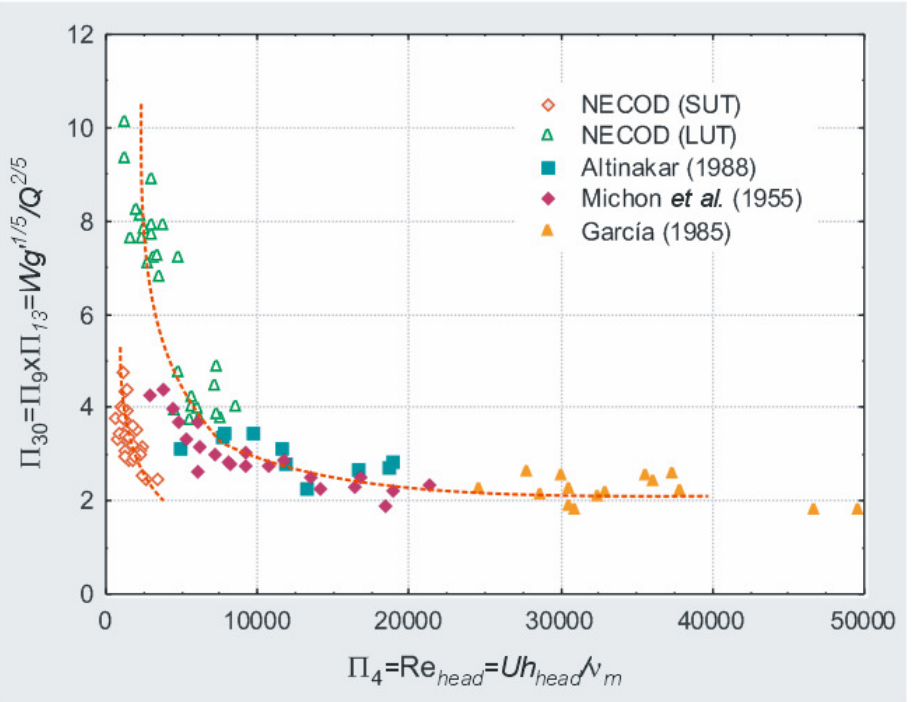
DIMENSIONAL ANALYSIS

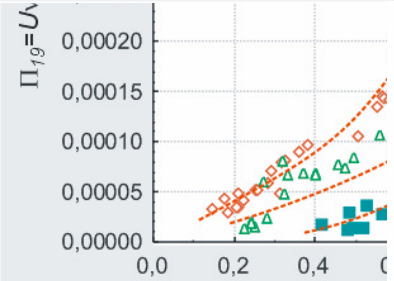
PHYSICAL MODELS









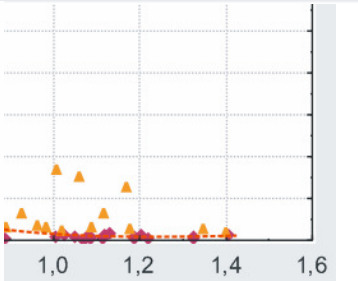


WALL EFFECT:

Inhibiting the turbulent effects in small tanks

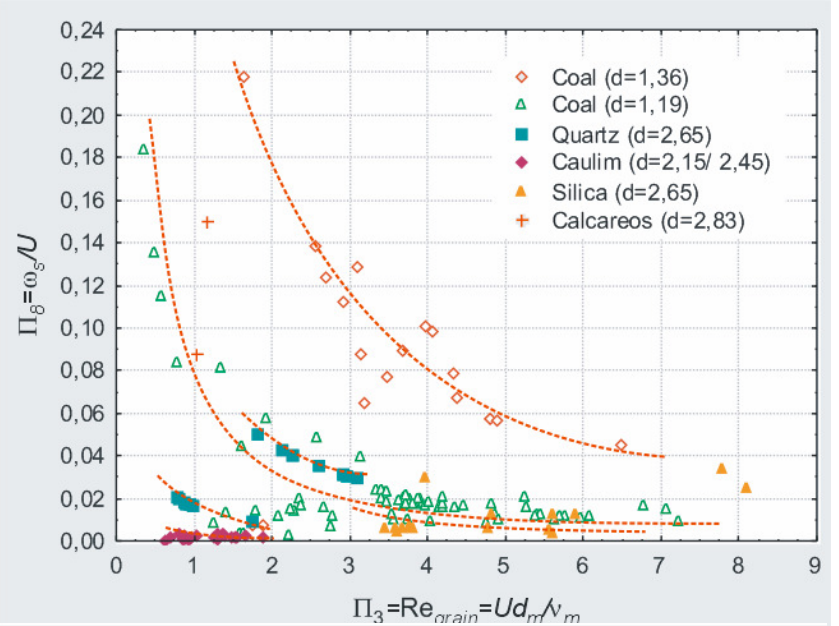
LONG PHYSICAL MODELS:

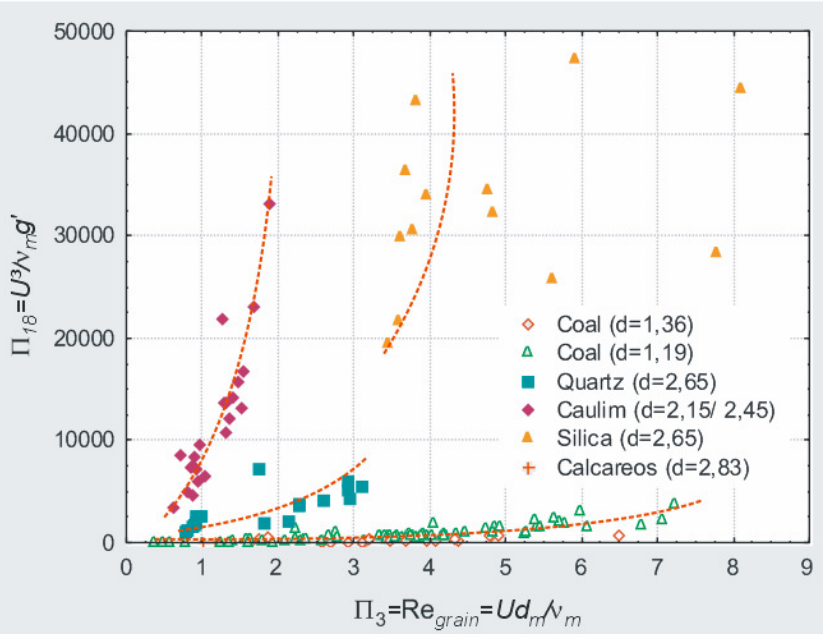
Long tanks tends to reach steady-stade regime

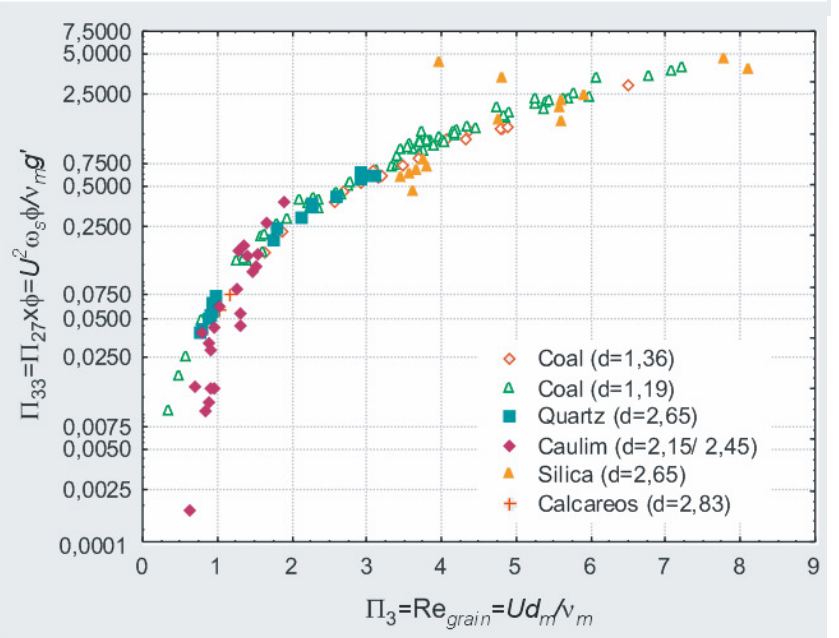


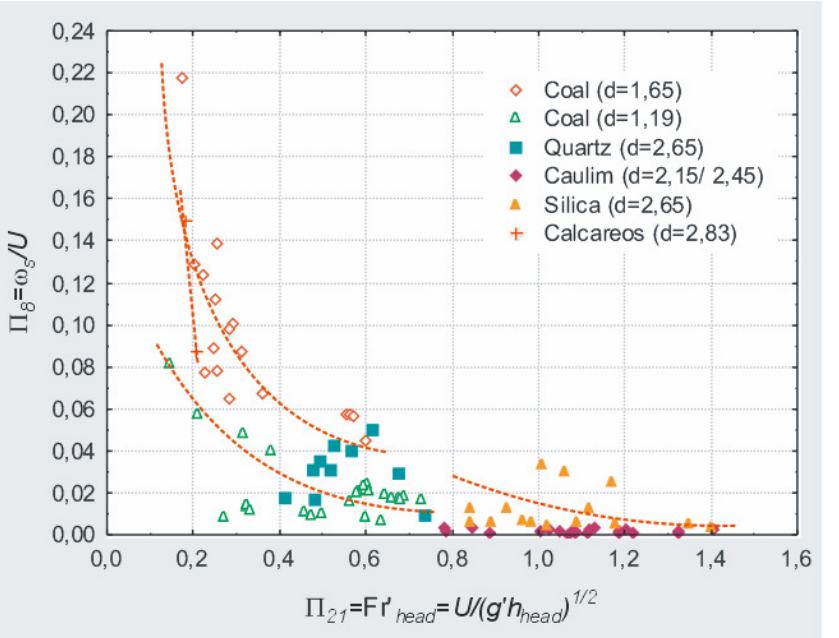
DIMENSIONAL ANALYSIS

SEDIMENTS CHARACTERISTICS



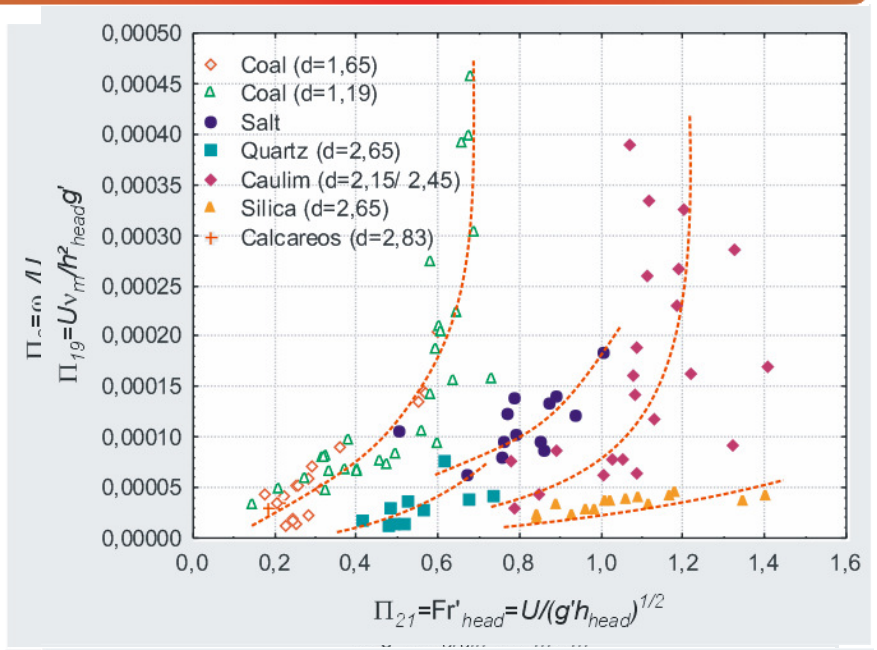


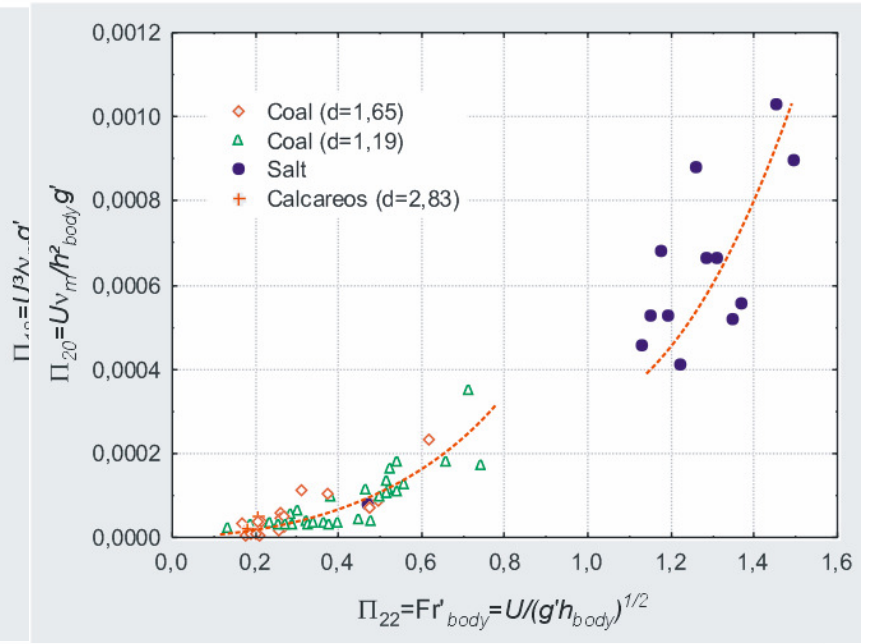


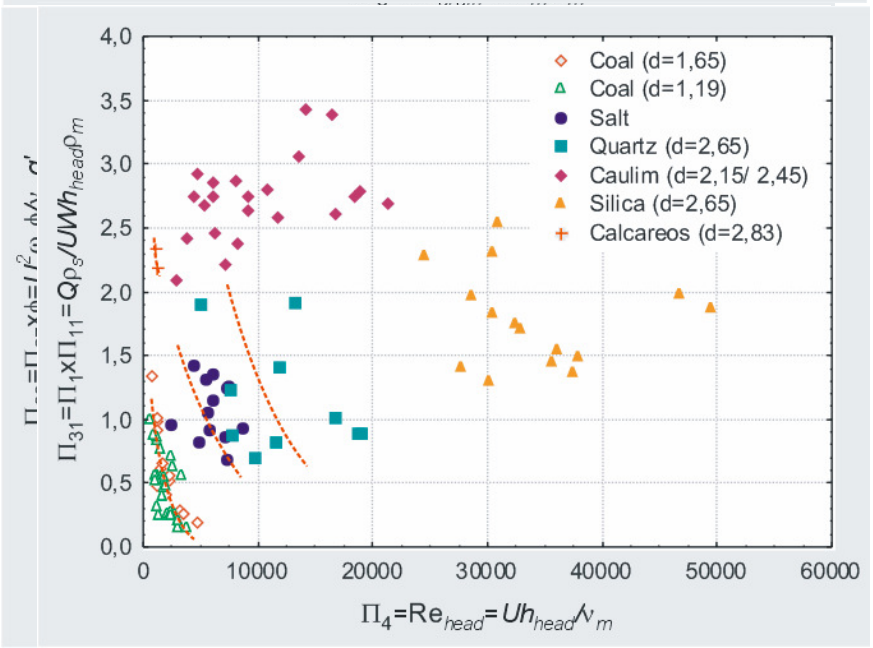


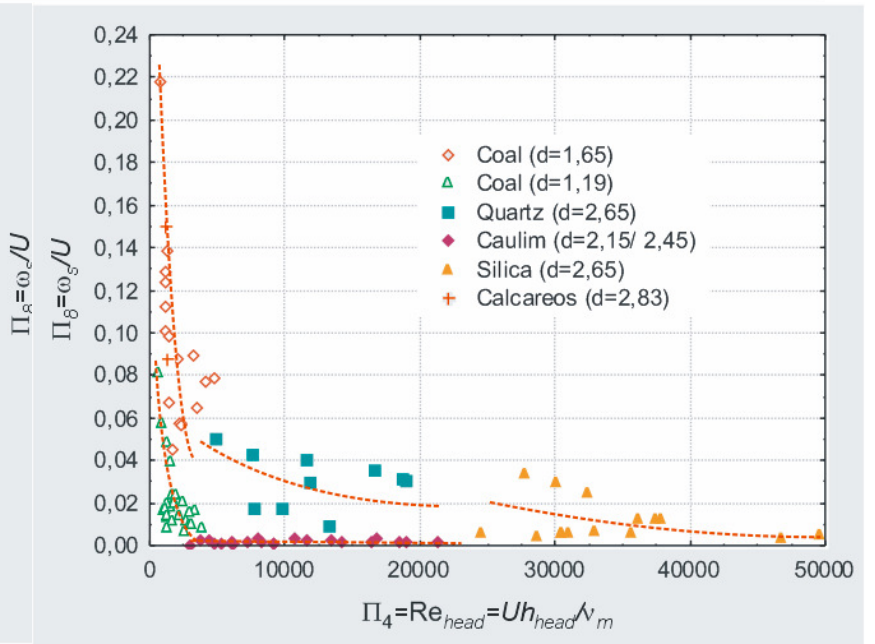
DIMENSIONAL ANALYSIS

SEDIMENTS CHARACTERISTICS



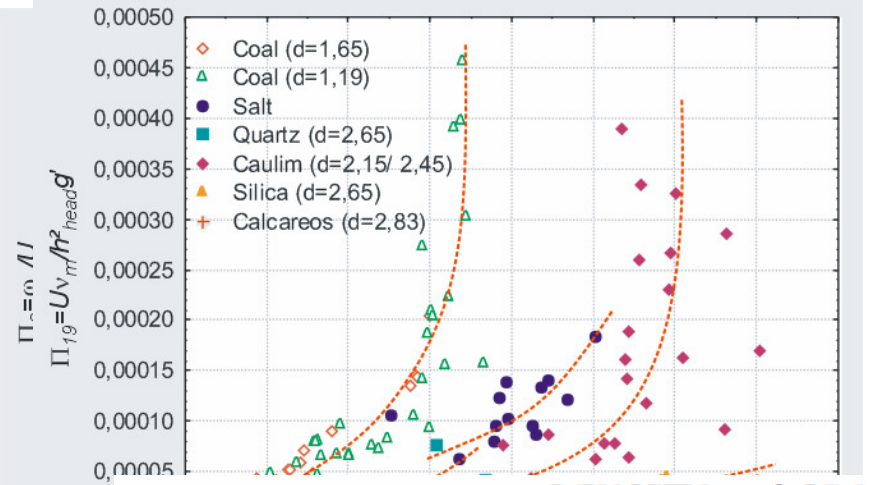


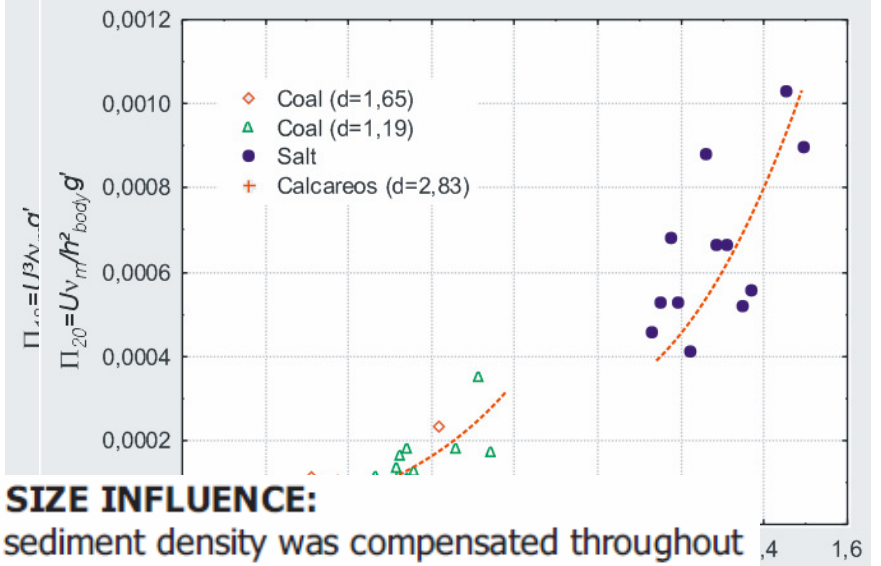




DIMENSIONAL ANALYSIS

SEDIMENTS CHARACTERISTICS



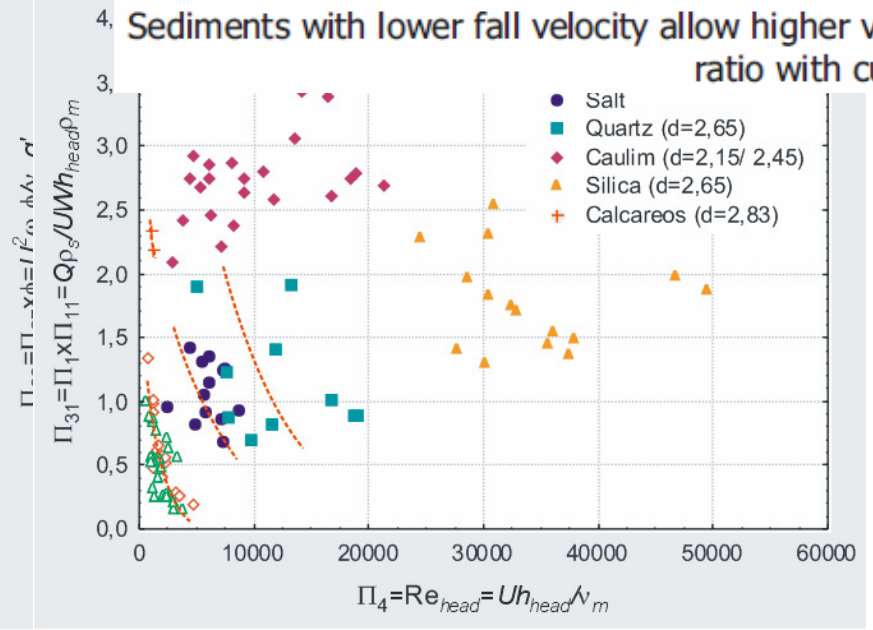


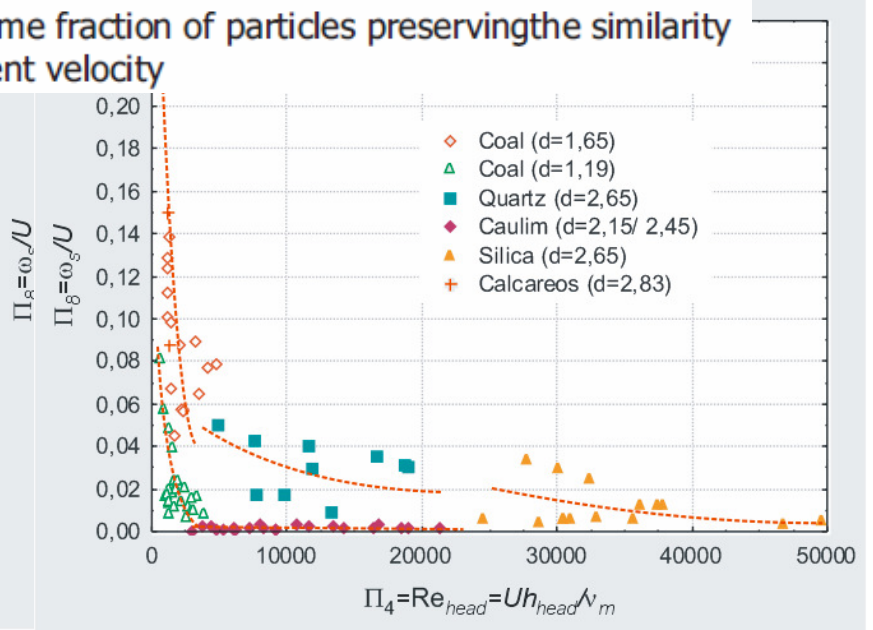
DENSITY and GRAIN SIZE INFLUENCE:

The similarity conditions was maintained when the sediment density was compensated throughout the use of finer sediment (Coal)

FALL VELOCITY INFLUENCE:

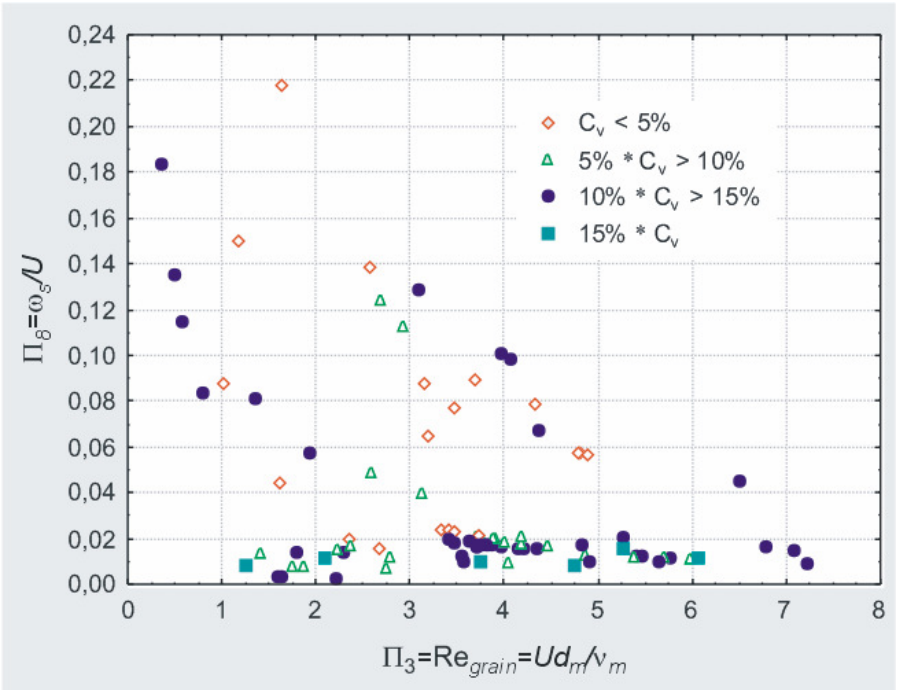
Sediments with lower fall velocity allow higher volume fraction of particles preservingthe similarity ratio with current velocity

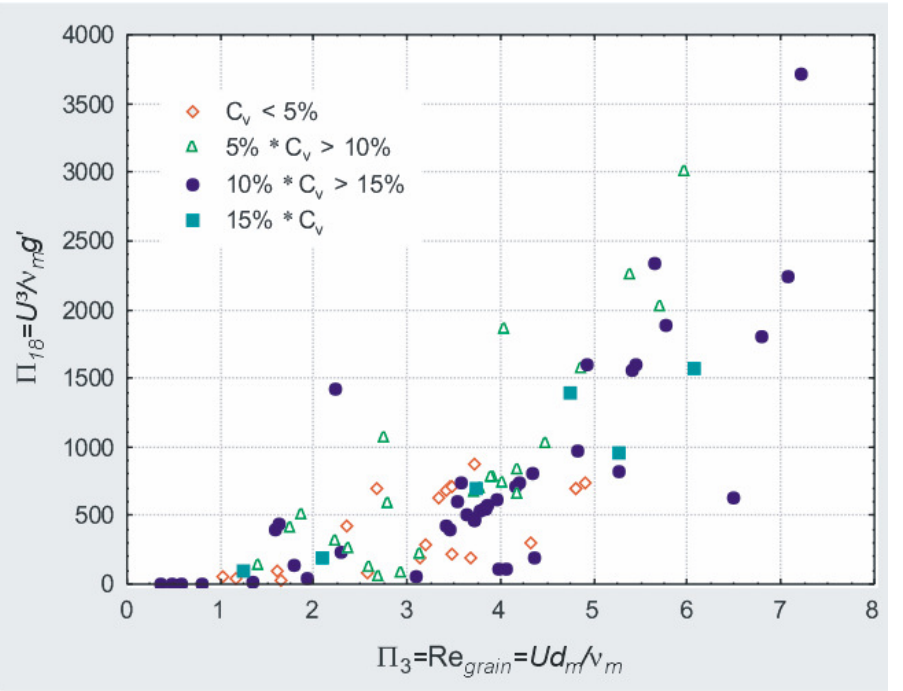




DIMENSIONAL ANALYSIS

INLET CONDITIONS





$$\Pi_8 = \frac{\omega_s}{U}$$

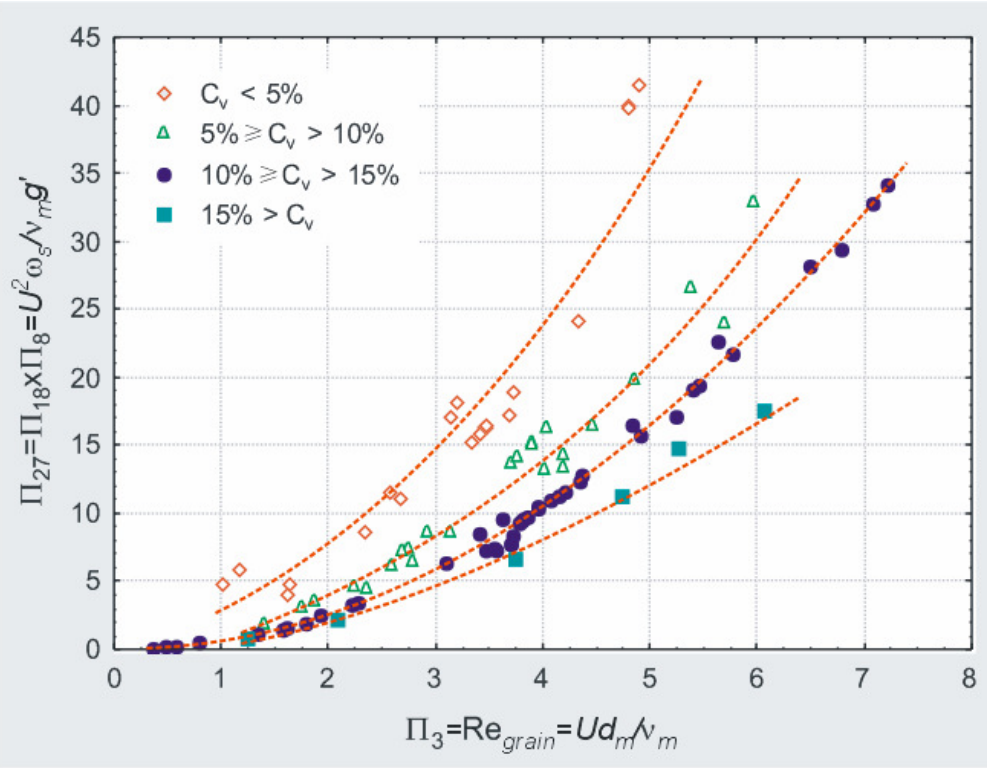
$$\Pi_{18} = \mathrm{Ke} = \frac{U^3}{\nu_m g'}$$

$$\Pi_{27} = \Pi_{18} \times \Pi_8 = \frac{U^2 \omega_s}{\nu_m g'}$$

DIMENSIONAL ANALYSIS

INLET CONDITIONS

$$\Pi_{27} = \Pi_{18} \times \Pi_8 = \frac{U^2 \omega_s}{\nu_m g'}$$

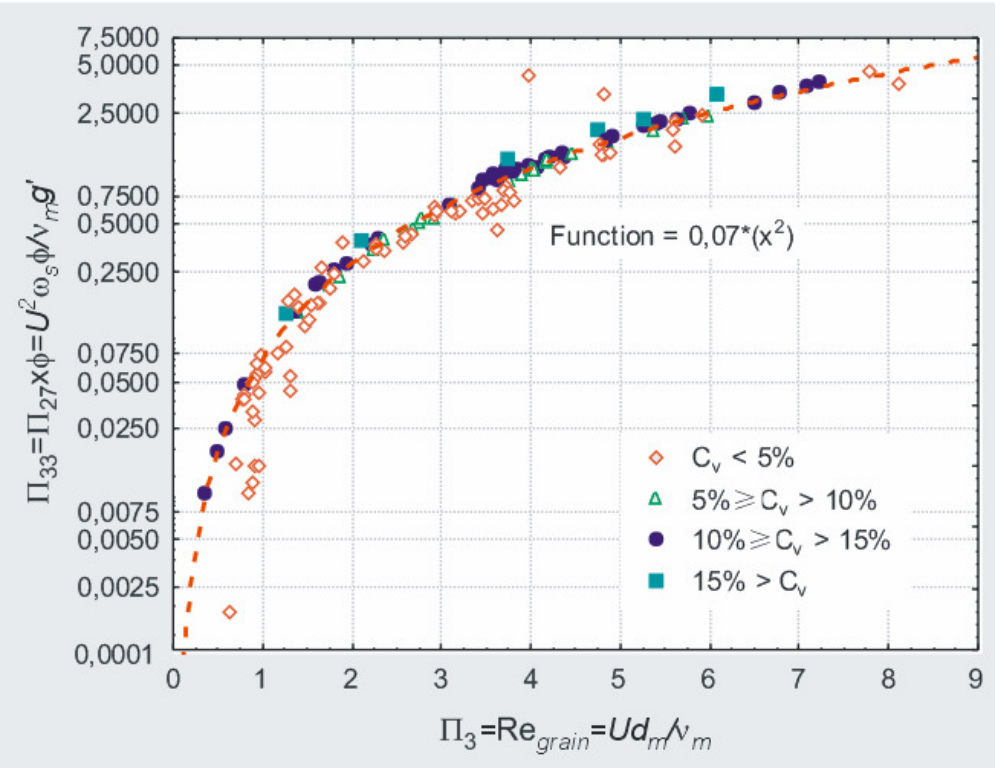


$$\left(\Pi_{33} = \Pi_{27} \times \phi = \frac{U^2 \omega_s \phi}{\nu_m g'}\right) \times \left(\Pi_3 = \frac{U d_m}{\nu_m}\right)$$

DIMENSIONAL ANALYSIS

INLET CONDITIONS

$$\left(\Pi_{33} = \Pi_{27} \times \phi = \frac{U^2 \omega_s \phi}{\nu_m g'}\right) \times \left(\Pi_3 = \frac{U d_m}{\nu_m}\right)$$



Including old studies data

$$\Pi_{33} \approx 0{,}07 \Pi_3^{\,2}$$

$$\frac{\omega_s \phi}{g'} \approx 0{,}07 \frac{d_m}{\nu_m}$$

$$\frac{\omega_s}{d_m} \approx 0{,}07 \frac{g'}{\phi \nu_m}$$

Strong relation among inlet parameters

REGRESSION MODELS

Monomial Power-law models

$$\text{Dependent parameters} = f(\text{Independent parameters})$$

$$y = x_1^a x_2^b x_3^c$$

a, b, c : constants that was determined
x_1, x_2, x_3 : independent parameters that was alternated

1st Stage:
1 Dependent parameter vs.
1 Independent parameter

2nd Stage:
1 Dependent parameter vs.
2 Independent parameter

3rd Stage:
1 Dependent parameter vs.
3 Independent parameter

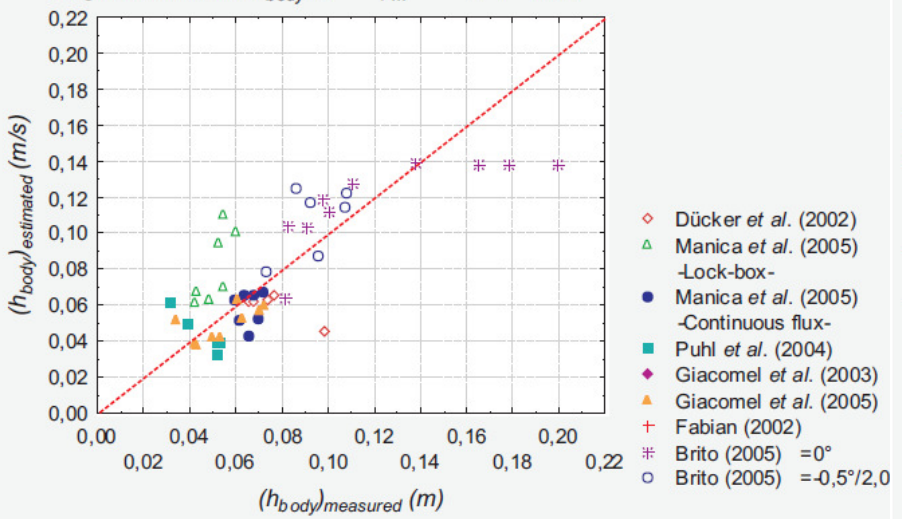
Dependent parameters:
- Current velocity (U)
- Current Head Height (h_{head})
- Current Body Height (h_{body})

Independent parameters:
- Grain size (d_m)
- Fal velocity (ω_s)
- Mixture density (ρ_m)
- Reduced gravity $(g`)$
- Dynamic viscosity (μ_m)
- Kinematic viscosity (ν_m)
- Volumetric concentration (C_v)
- Flow rate (Q)
- Linear flow rate (q)

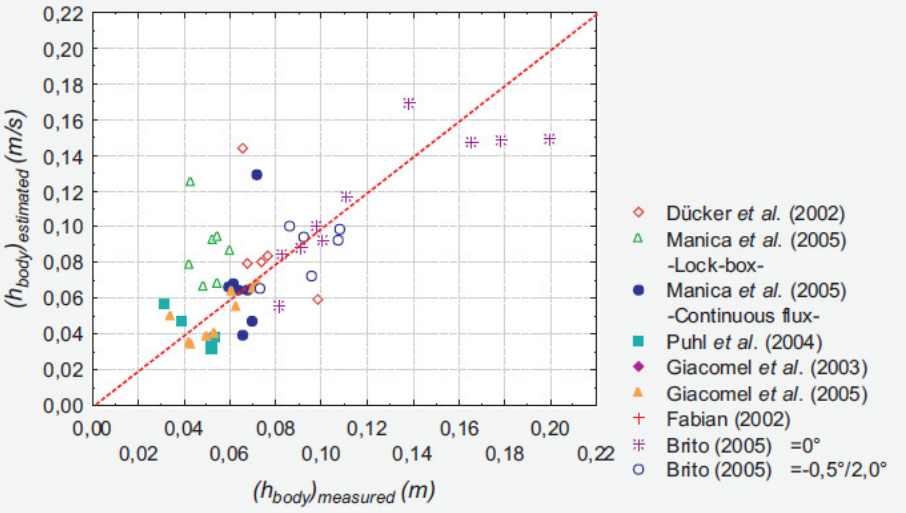
REGRESSION MODELS

CURRENT BODY REGRESSION MODELS

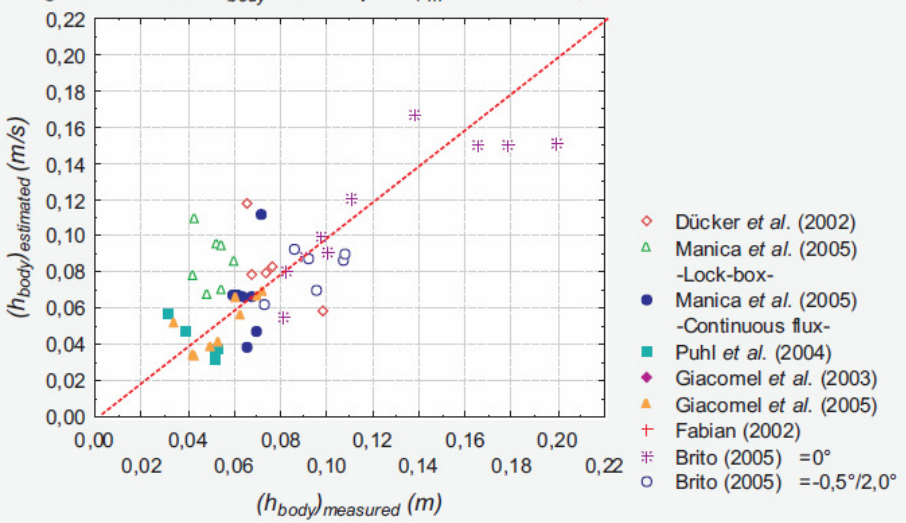
Regression model: $h_{body}=Q^{0,891}\mu_m^{-0,774}$.:. $r^2=0,60$



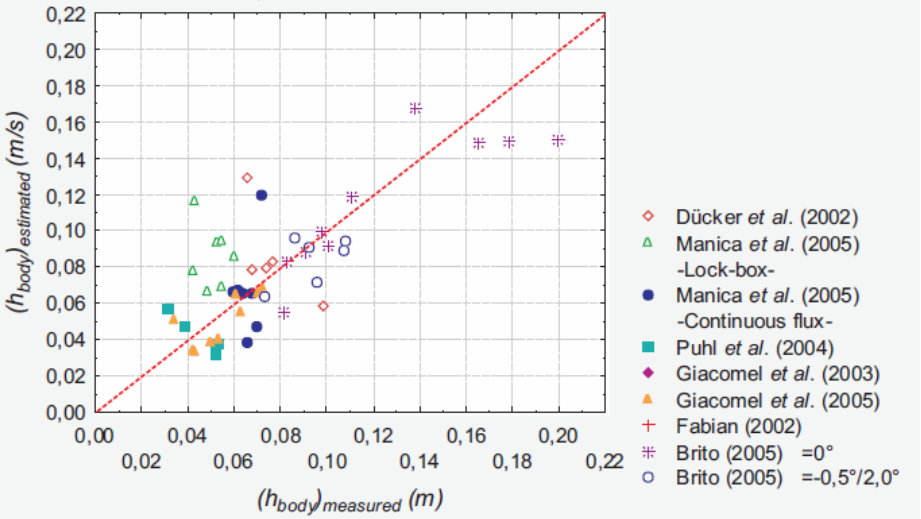
Regression model: $h_{body}=Q^{0,823}C_v^{-0,435}\rho_m^{0,787}$.:. $r^2=0,70$



Regression model: $h_{body}=Q^{0,826}C_v^{-0,312}\mu_m^{-0,777}$.:. $r^2=0,70$



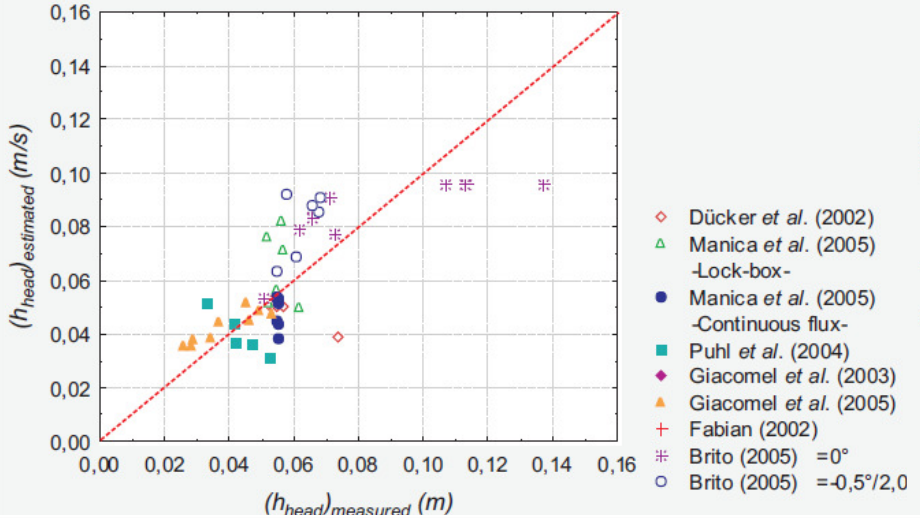
Regression model: $h_{body}=Q^{0,825}C_v^{-0,373}\nu_m^{0,391}$.:. $r^2=0,70$



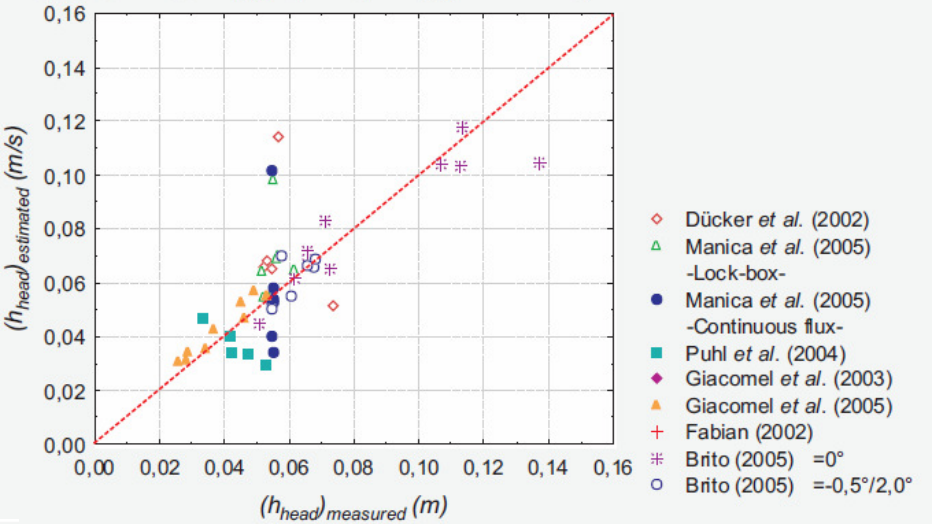
REGRESSION MODELS

CURRENT HEAD REGRESSION MODELS

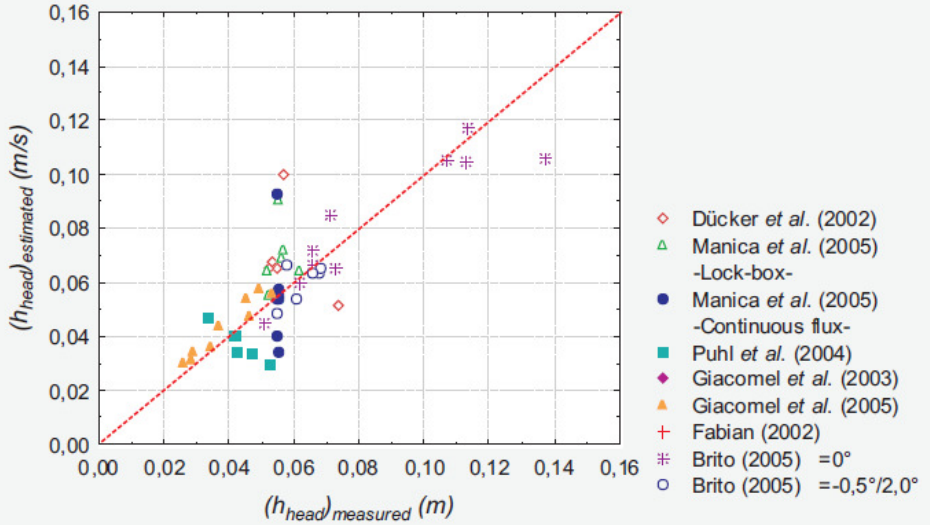
Regression model: $h_{head}=Q^{0,706}\mu_m^{-0,498}$.:. $r^2=0,59$



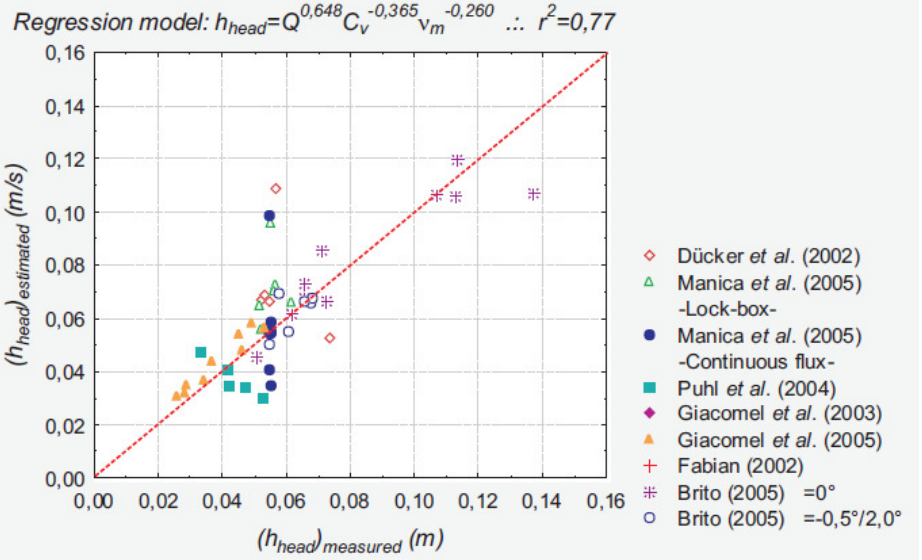
Regression model: $h_{head}=Q^{0,648}C_v^{-0,407}\rho_m^{0,524}$.:. $r^2=0,77$



Regression model: $h_{head}=Q^{0,648}C_v^{-0,324}\mu_m^{-0,515}$.:. $r^2=0,77$

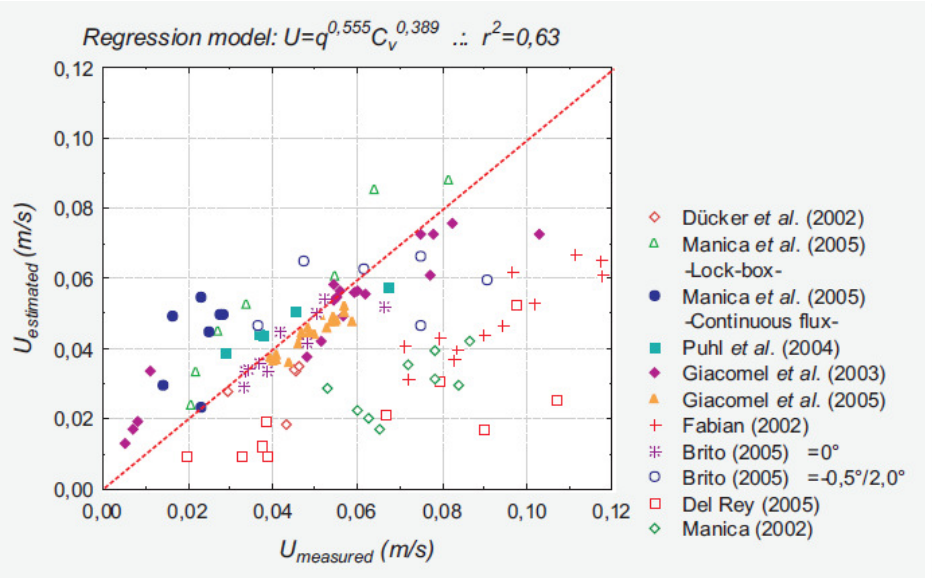


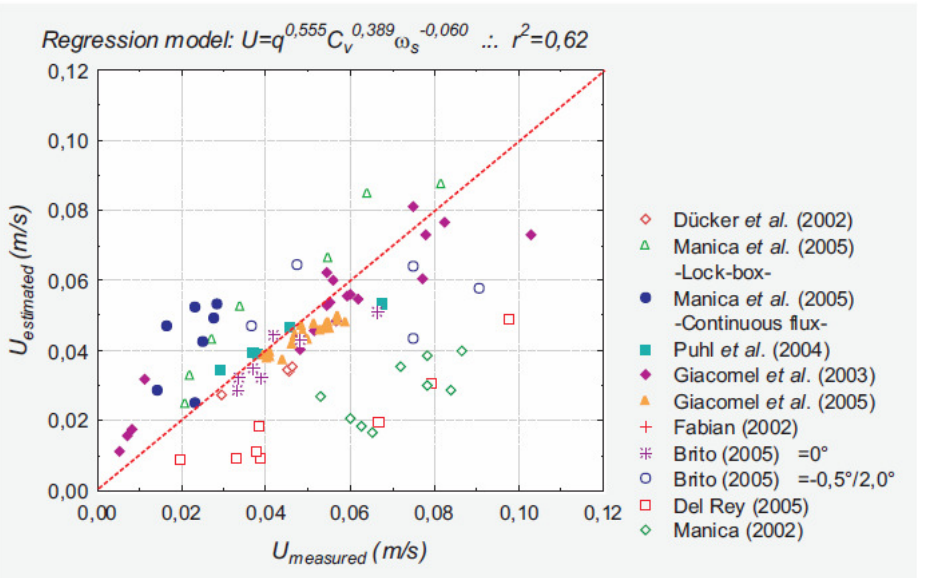
Regression model: $h_{head}=Q^{0,648}C_v^{-0,365}\nu_m^{-0,260}$.:. $r^2=0,77$



REGRESSION MODELS

VELOCITY REGRESSION MODELS





AMONG THE REGRESSION MODELS:

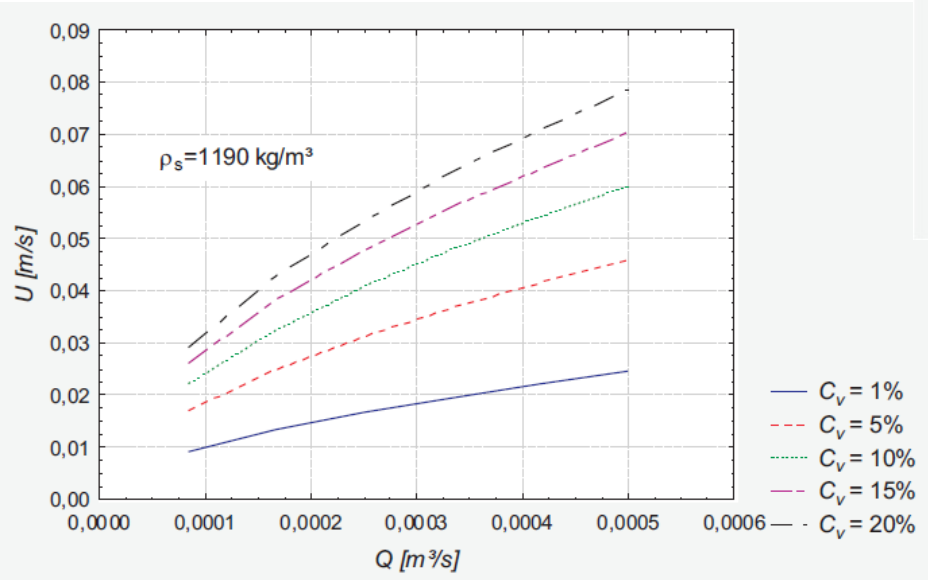
Flow rate, volumetric concentration and mixture physical proprieties were the parameters most sensitive to the regression models.

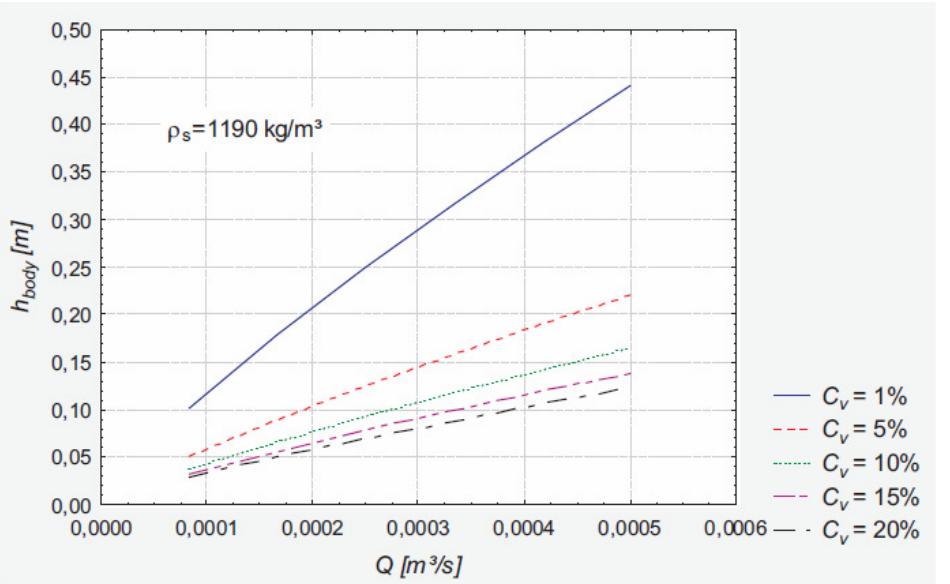
Regression models obtained not incorporate the similarity laws, then cannot be applied to physical models that are not similar to the unidirectional tanks.

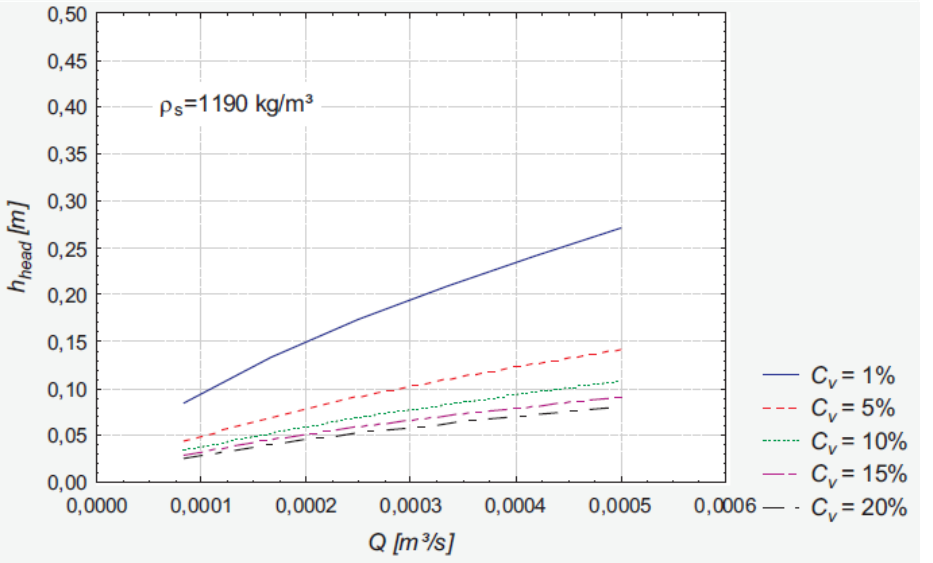
REGRESSION MODELS

PARAMETERS PREDICTION MODELS

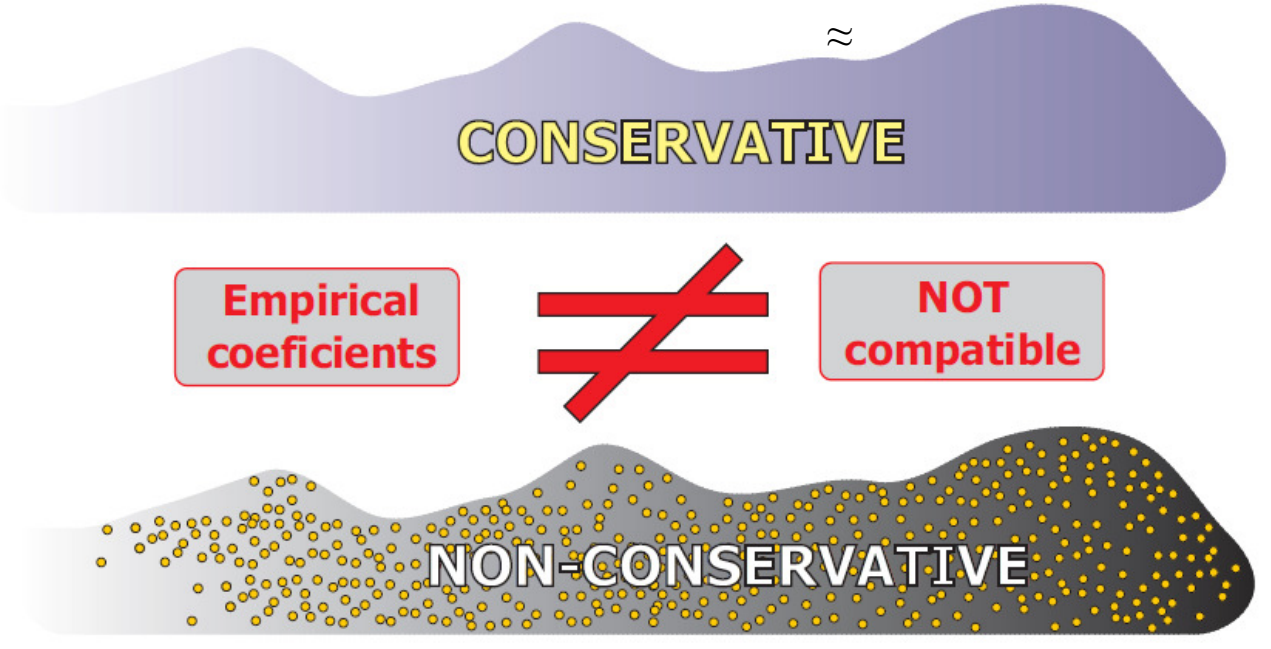
Just for similar physical models





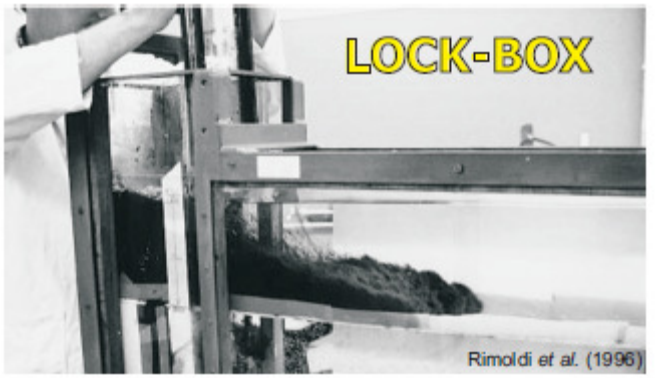


FINAL REMARKS



Simpson (1997)

FINAL REMARKS



≈

DYNAMICS

≠

Cannot be aproximated

Simpson (1997)

FINAL REMARKS

$\approx$

SEDIMENTS CHARACTERISTICS

SIMILARITY CONDITION

$$\Pi_8 = \frac{\omega_s}{U}$$

HEAVIER BUT FINER

OK

LIGHTER BUT COARSE

CONTINUOUS FLOW

Simpson (1997)

FINAL REMARKS

≈

SEDIMENTS CHARACTERISTICS

HEAVIER BUT FINER

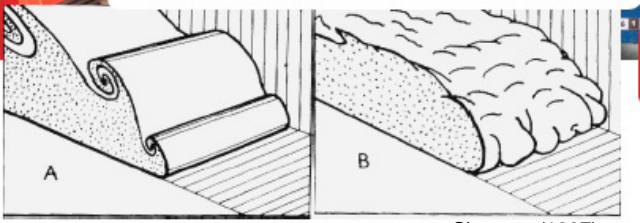
CONTINUOUS FLOW

SIMILARITY CONDITI

$$\Pi_8 = \frac{}{}$$

3D INSTABILITIES

INHIBITED



Simpson (1997)

FINAL REMARKS

≈

SEDIMENTS CHARACTERISTICS

HEAVIER BUT FINER

CONTINUOUS FLOW

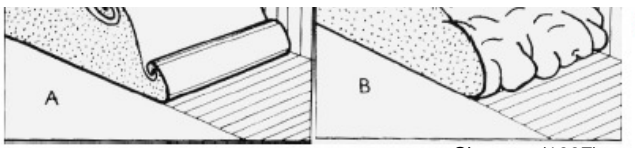
SIMILARITY CONDITI

$$\Pi_8 = \frac{}{}$$

Initial Fr' $= \frac{\text{Inertial forces}}{\text{Buoyant forces}}$

CONCENTRATION MAINTENANCE CAPACITY

Flow Fr' $= \frac{\text{Inertial forces}}{\text{Buoyant forces}}$



Simpson (1997)

FINAL REMARKS

NATURAL PARAMETERS or MODELING ESTIMATES

$$\frac{\omega_s}{d_m} \approx 0{,}07 \frac{g'}{\nu_m}$$

REGRESSION MODELS

PARAMETERS PREDICTIONS

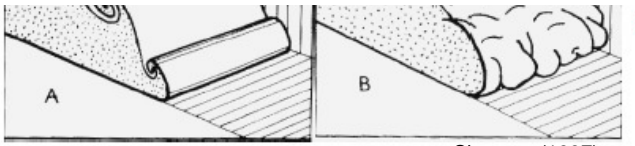
SIMILARITY CONDITI

$$\Pi_8 = \frac{}{}$$

Initial Fr' = Inertial forces / Buoyant forces

CONCENTRATION MAINTENANCE CAPACITY

Flow Fr' = Inertial forces / Buoyant forces



Simpson (1997)

FINAL REMARKS

NATURAL PARAMETERS

$$\frac{\omega_s}{d_m} \approx 0{,}07 \frac{g'}{\nu_m}$$

PARAMETERS

CTIONS

MODE

ESTIM

SIMILAR

CONDITI

$$\Pi_8 = \frac{\ldots}{\ldots}$$

Initial Fr'

$$\frac{\text{Intertial force}}{\text{Buoyant force}}$$

OUS

FLOW

$$\frac{\text{Intertial forces}}{\text{Buoyant forces}}$$

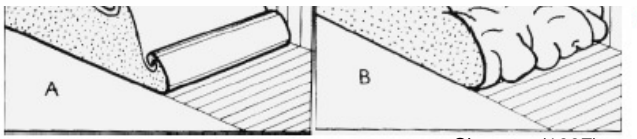
NON-DIMENSIONAL GROUPS

$$\Pi_3 = \mathrm{Re}_{grain} = \frac{U d_m}{\nu_m}$$

$$\Pi_4 = \mathrm{Re}_{head} = \frac{U h_{head}}{\nu_m}$$

$$\Pi_{21} = \mathrm{Fr}'_{head} = \frac{U}{\sqrt{g' h_{head}}}$$

Presented better similarity conditions



Simpson (1997)