

# Particle Mass Transfer in Pipelines

By

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# Agenda

- The importance of the task
- Assumptions
- Stopping distance model
- Transport mechanisms
- Particle sizes in oil and gas production
- Basic calculations
- Uncertainties
- Discussion
- Conclusion

# Importance of the task

- Find the deposition rate of particles with different sizes
- Predict future pressure loss
- Reduced flowrate
- Schedule interventions

# Assumptions

- Dilute mixture
- The particle motion depends on the fluid flow field, not vice versa
- 100% stickability

# Stopping distance model

- Defined: The distance a particle will travel through a stationary fluid
- In turbulent flow the stationary fluid is located in the viscous sublayer close to the wall
- “The particle relaxation time,  $\tau$ , is a measure of particle inertia and denotes the time scale with which any slip velocity between the particles and the fluid is equilibrated” (Guha, 2008)

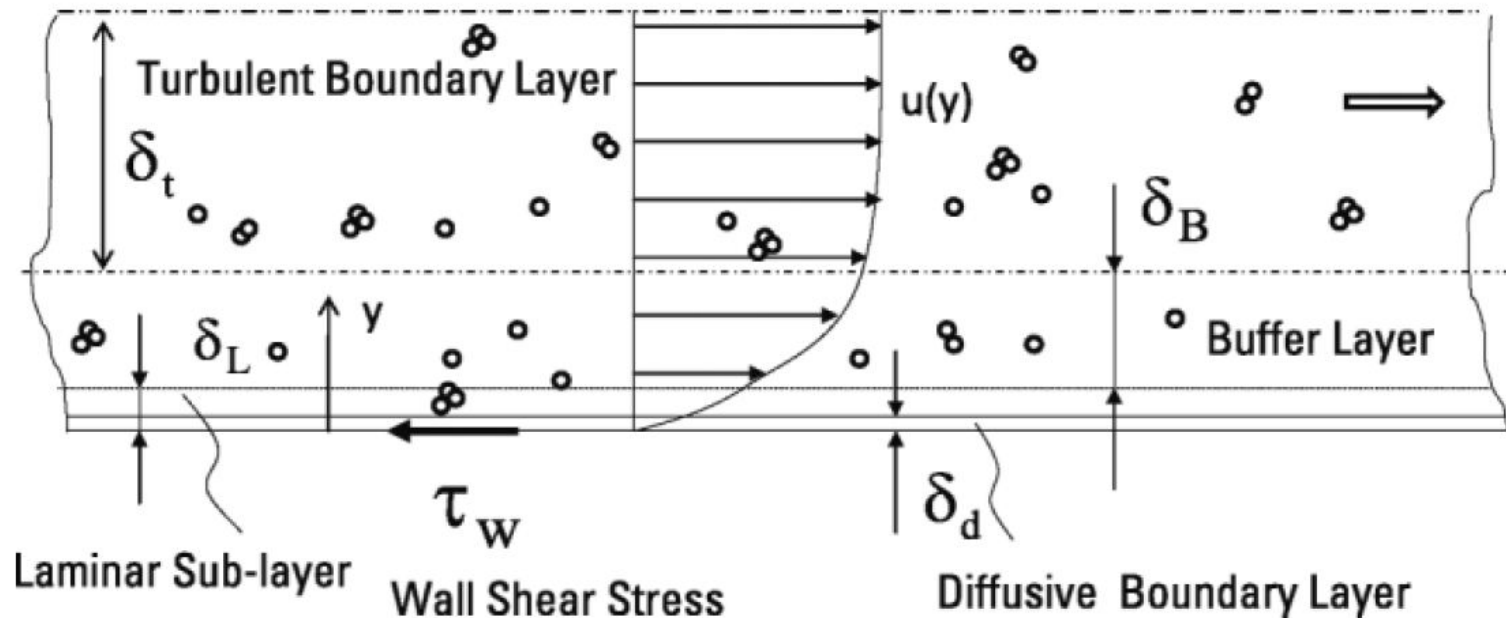
$$\lambda = \tau_p \cdot u_i$$

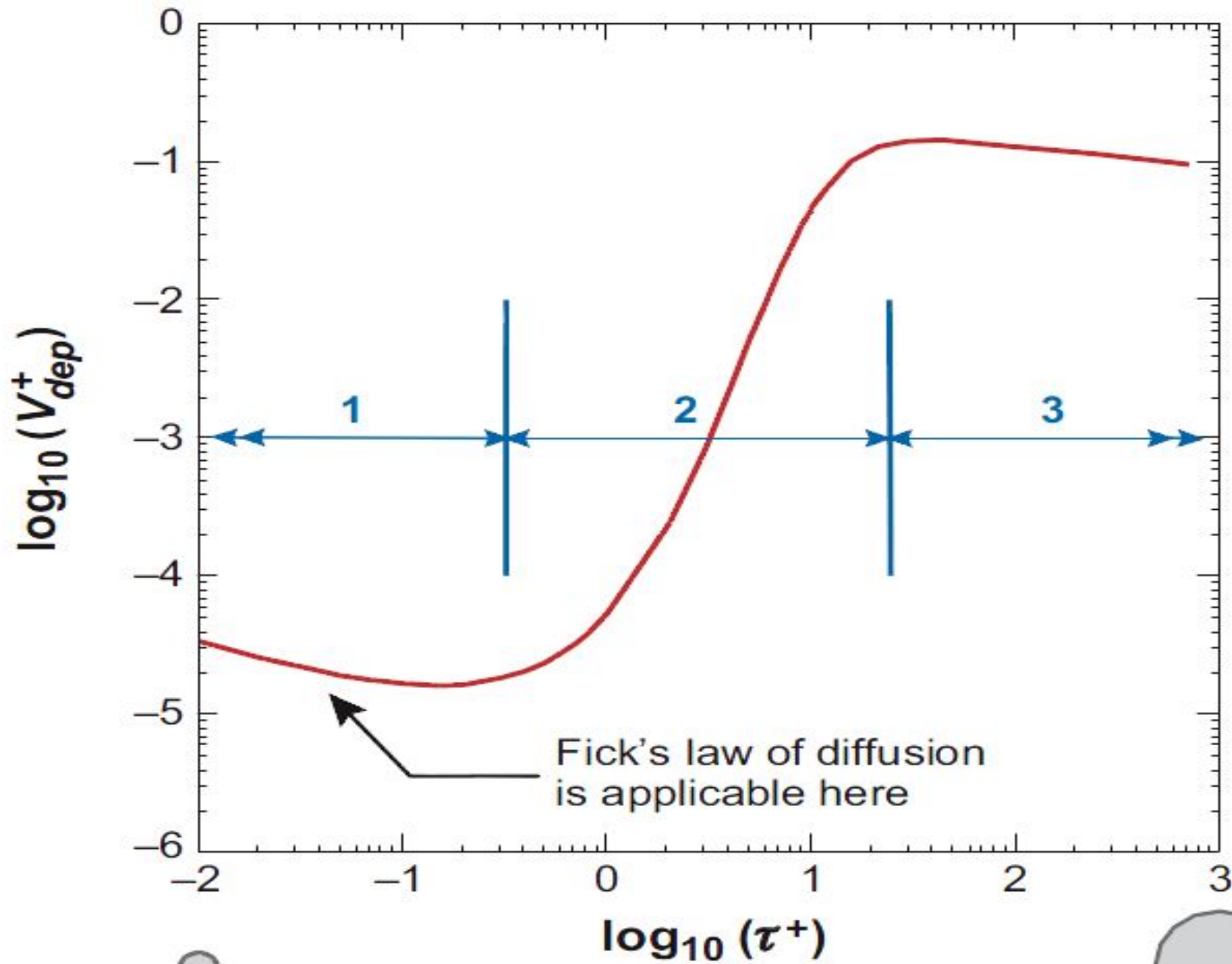
$$\tau_p = \frac{\rho_p d_p^2}{18\mu}$$



- Results from deposition calculations and experiments are often presented as curves of nondimensional deposition velocity and nondimensional particle relaxation time

$$\tau_p^+ = \frac{\tau_p \rho (u^*)^2}{\mu} \quad u_d = \frac{J}{C_p} \quad u_d^+ = \frac{u_d}{u^*}$$





Small particles

Deposition regime model (Guha, 2008)

Large particles

# Dominating transport mechanisms

- Diffusion regime:
  - Turbulent diffusion
  - Brownian diffusion
- Inertia regime:
  - Turbophoresis
  - Brownian diffusion
- Impaction regime:
  - Momentum from eddies in turbulent core

$$\tau_p^+ < 0,1$$

$$0,1 < \tau_p^+ < 10$$

$$\tau_p^+ > 10$$



# Other transportation mechanisms

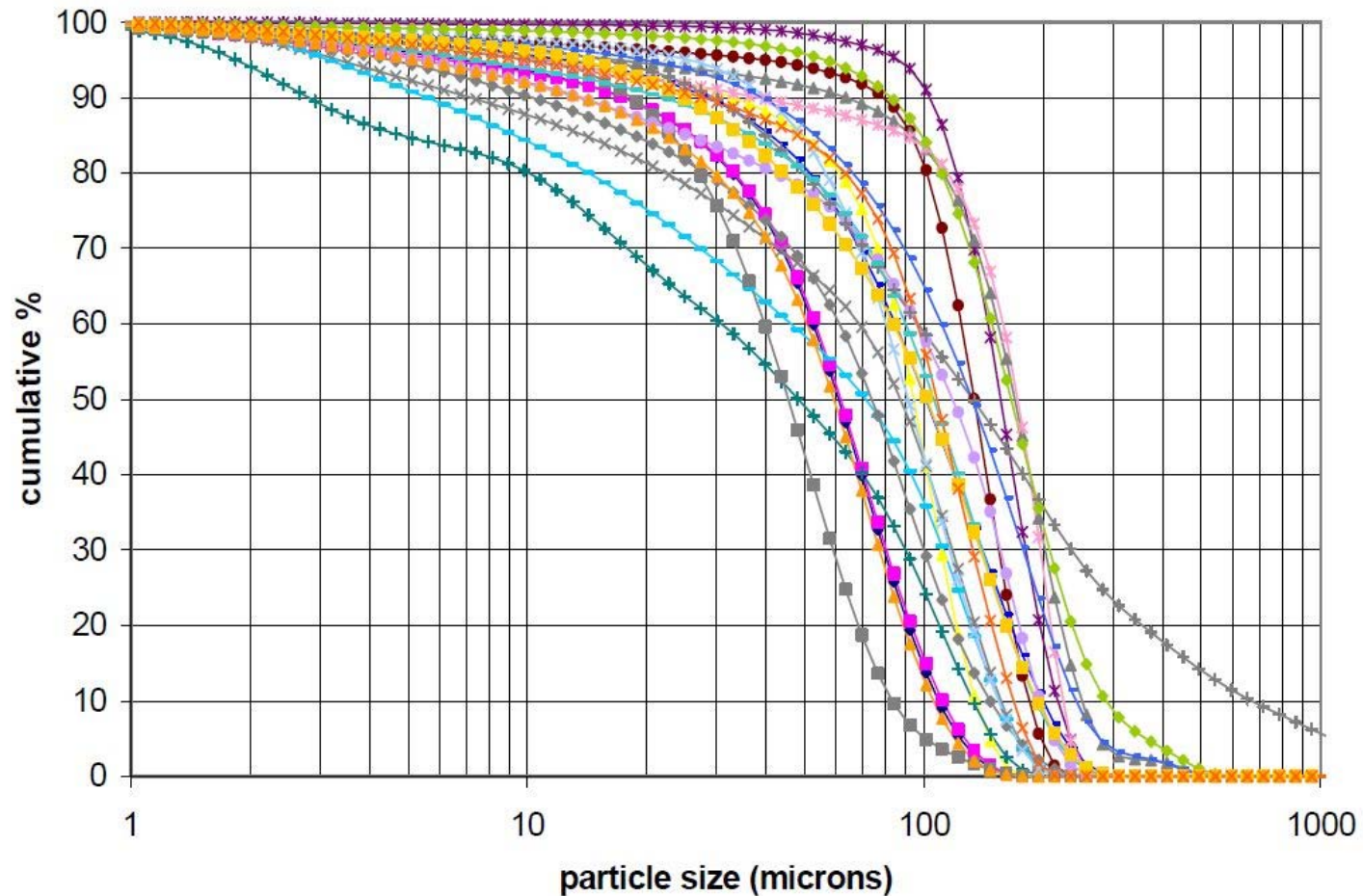
- Thermophoresis:
  - Particles diffuse due to temperature gradients, from hot to cold
- Electrostatics:
  - Particles diffuse due to electrical charges
- Gravitational settling:
  - In horizontal pipeflow gravity can be a dominating transport mechanisms for particles in inertia and impaction regime

# Common particles and particle sizes in oil and gas production

- Sand production from the reservoir
  - $d_s \sim 100\mu\text{m}-300\mu\text{m}$  (Tracy Ballards et al. 2003)
- Asphaltenes precipitating from crude oil
  - $d_a \sim 1\mu\text{m}-50\mu\text{m}$  (Gudmundsson, Akbarzadeh et al. 2007)
- Wax crystallization
  - $d_w \sim 1\mu\text{m}-10\mu\text{m}$  (Gudmundsson, Bacon et al. 2009)

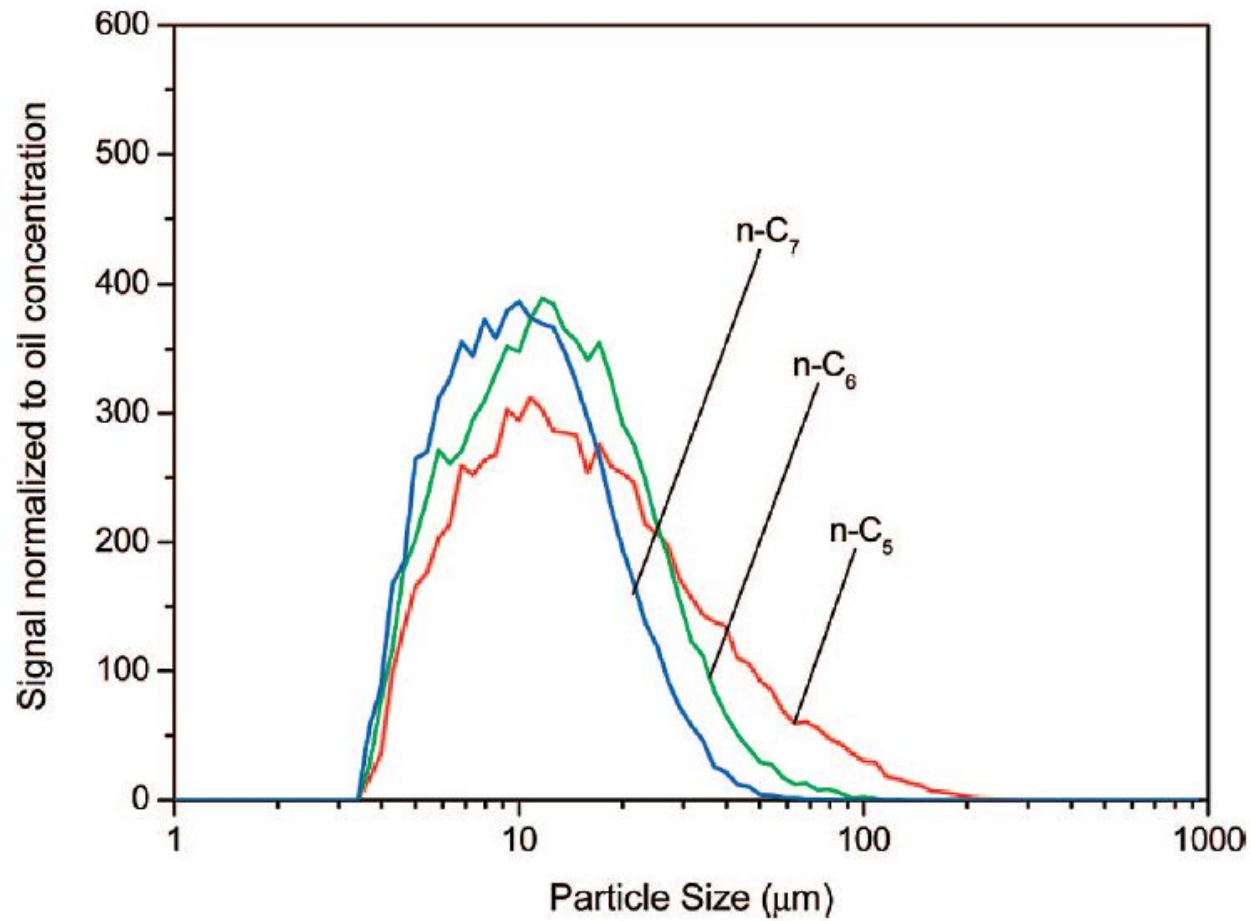
# Reservoir sand particle size distribution

Tracy Ballars et al.



# Asphaltene particle size distribution

Calles et al. 2008



## Basic calculations

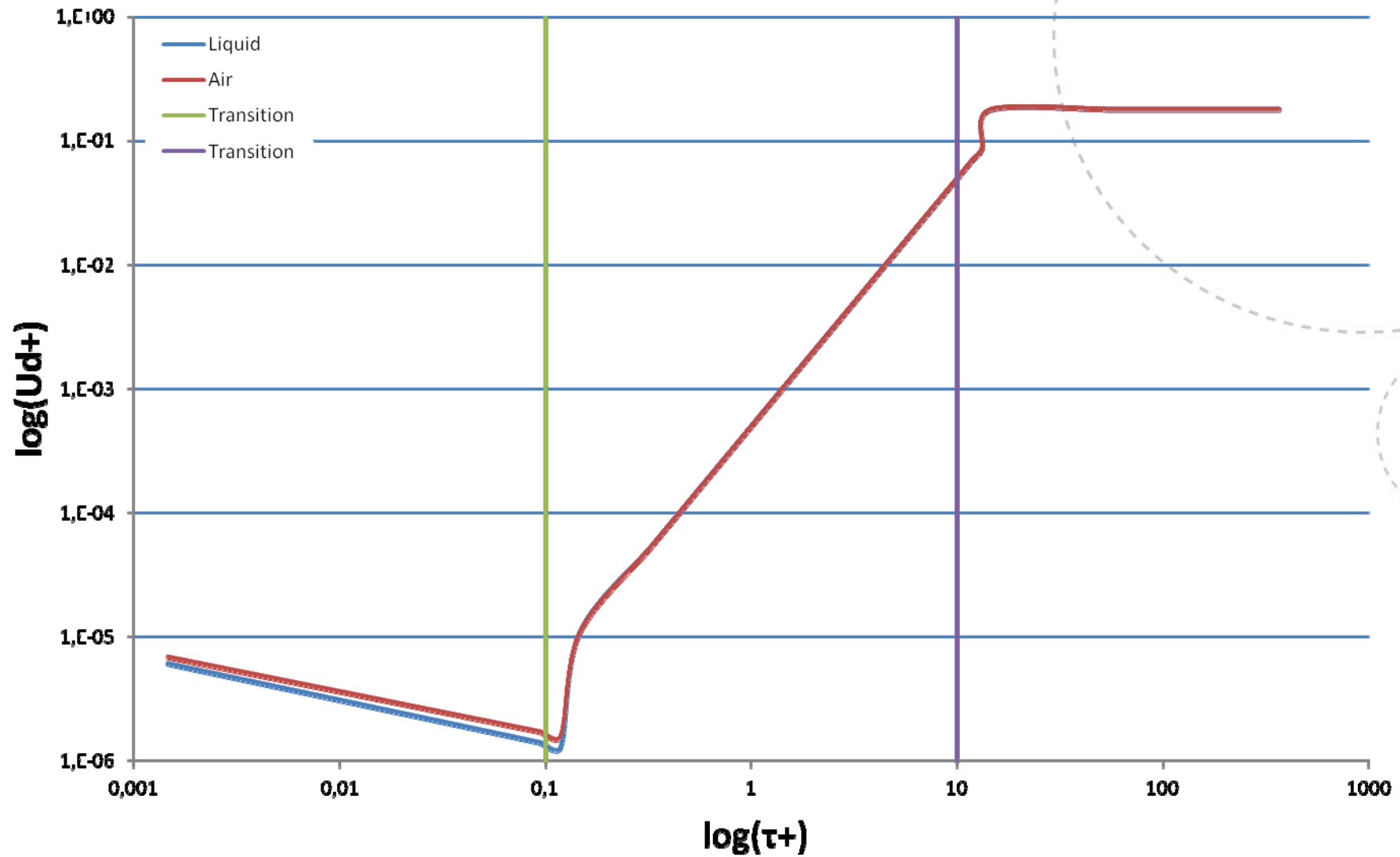
- Oil flow in subsea pipeline
- Empirical models from (Sippola&Nazaroff 2002)
- Based on experiments, but constants also from theoretical analysis coupled with simplifying mathematical approximations
- Compare empirical equations
- Sand- and asphaltene particles
- Vertical and horizontal flow

$$u_d^+ = k_1 Sc^{-2/3}$$

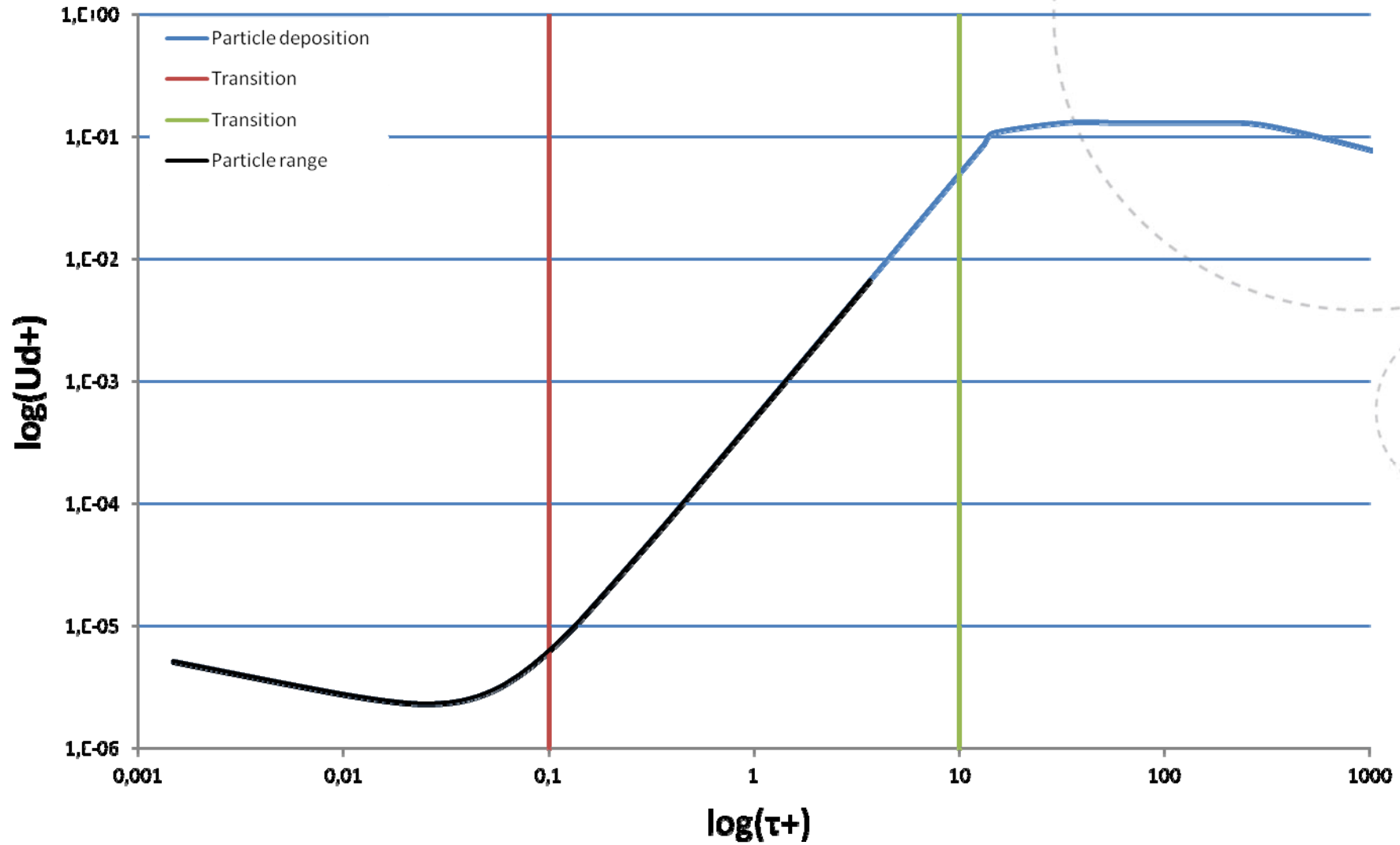
$$u_d^+ = k_2 (\tau_p^+)^2$$

$$u_d^+ = k_3$$

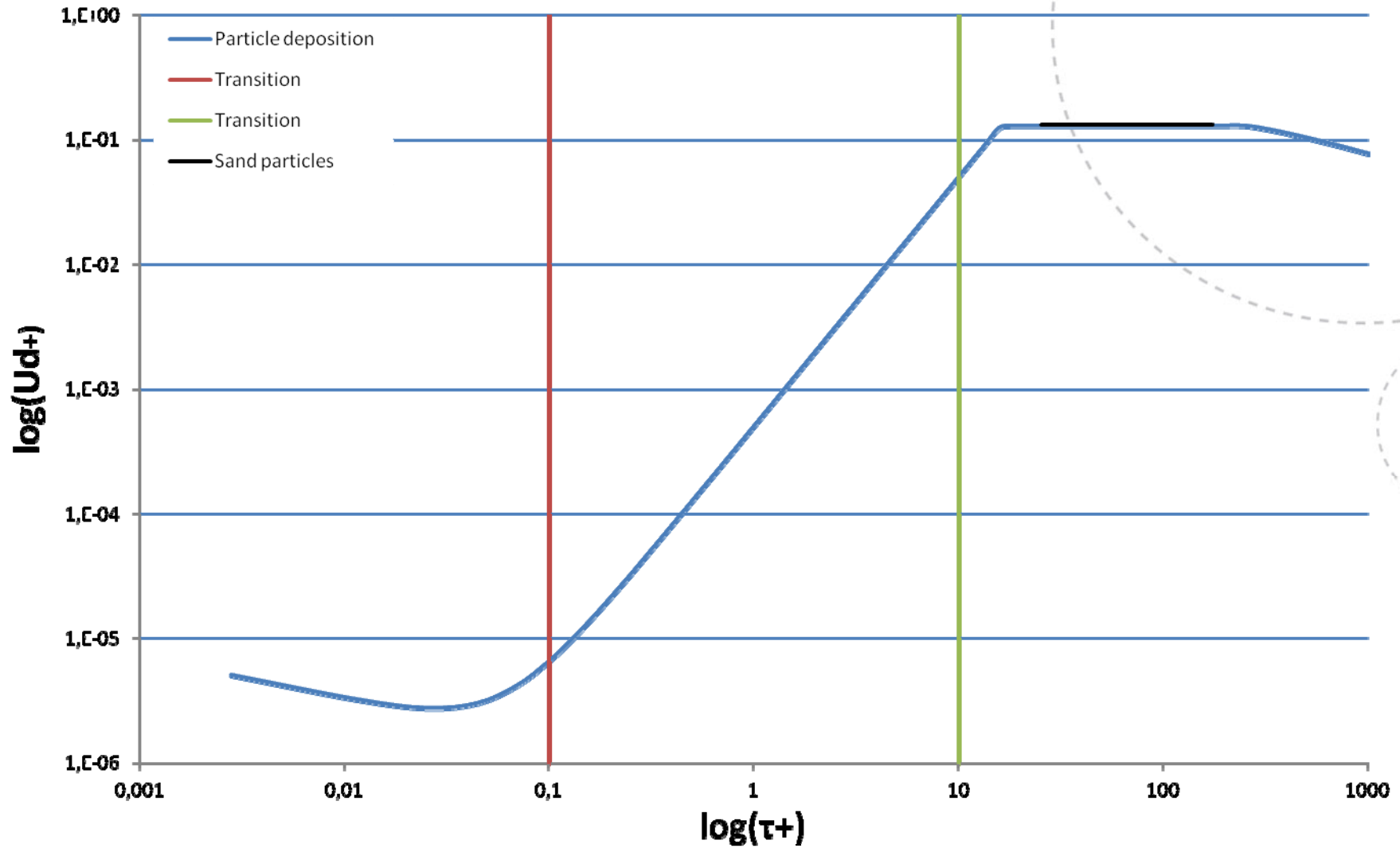
## Comparison liquid vs air



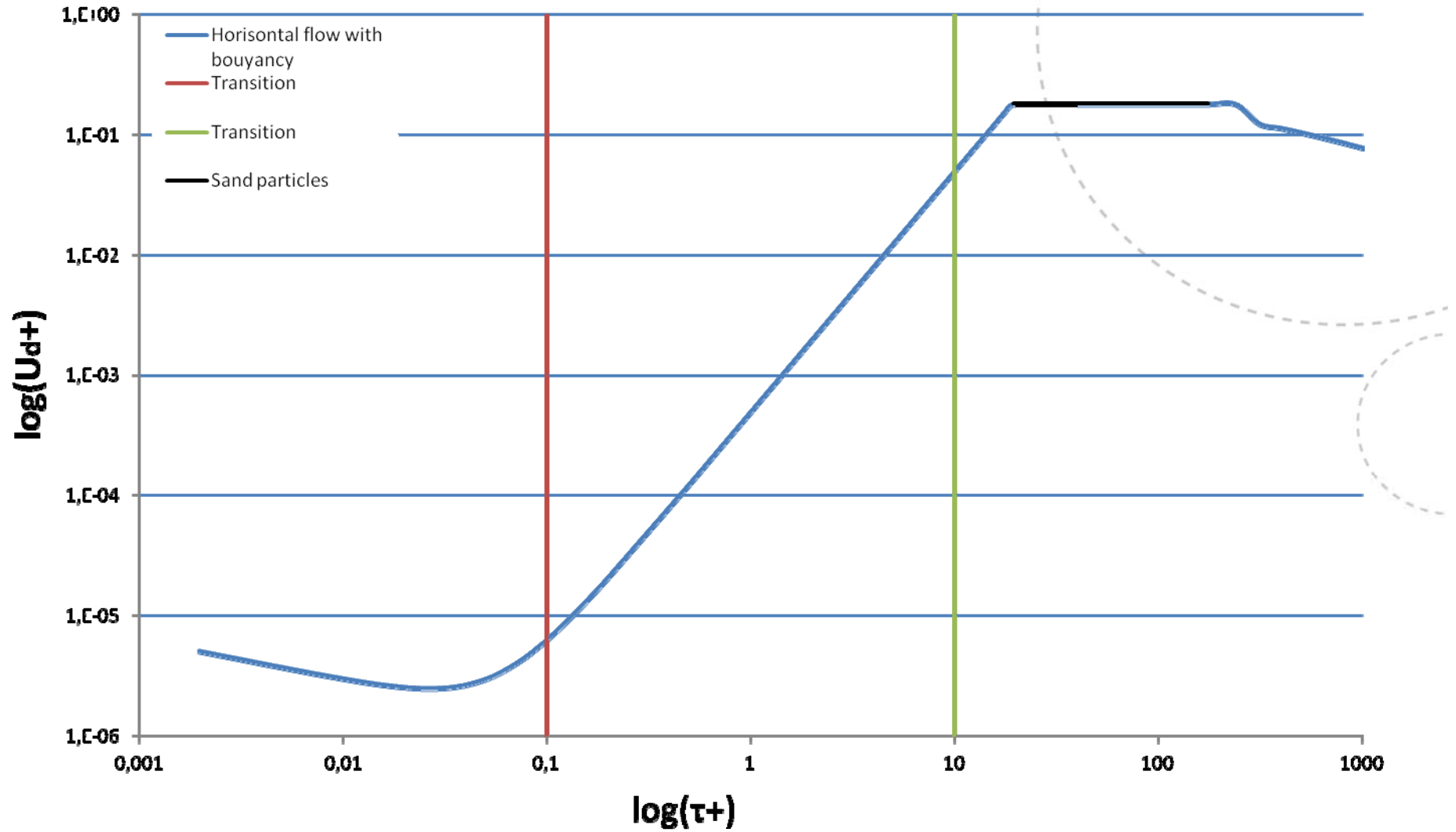
## Asphaltenes



## Sand particles, vertical pipe



## Sand particles, horizontal pipe



# Uncertainties

- Most of the work on this area is done on aerosols (Sippola and Nazaroff 2002)
- Not much work done on particles in liquid
- Not sure if constants are applicable to hydrosols
- Uncertain if empirical equations can produce accurate results for particles in fluid
- “Comparison of experimental data with theoretical predictions of deposition in the impaction regime indicates that deposition velocity from particles in liquid is much lower than particles in air” (Gudmundsson 1981)

# Discussion

- Because these constants are made for particles in air flow, they might be different for particles in fluid
- The small difference in diffusion deposition velocity from equations made for liquid and air flow, might indicate applicability in diffusion regime
- Gudmundsson reports of much lower  $U_{d+}$  in impaction regime for fluid flow (Gudmundsson 1981)
- Particles in liquid will be influenced by gravity and buoyancy, total contribution very small, more important for particles in horizontal gas flow
- Very little work done on particles in fluids, more research is needed
- All the discussed transport mechanisms are active in oil and gas production, but results might be different if the equations are not applicable
- Modern methods modeling particle mass transfer are Lagrangian and Eulerian

# Conclusions

- Most particle sizes in oil and gas production, which may deposit, are in the range:  $1\mu\text{m}$ - $300\mu\text{m}$
- All the transport mechanisms discussed are active in oil and gas transport, depends on particle size
- Small difference between empirical calculations for liquid and air in diffusion regime
- The contribution of gravity for liquid flow in horizontal pipes is negligible when buoyancy is accounted for
- Existing empirical models maybe more applicable to vertical flow and gas production
- Increased asphaltene deposition with lower pressure
- Sand particles will deposit at a faster rate than asphaltenes

# Thank you for your attention

Any questions?

# Data and formulas

Parameters					
Temperature	T	20	[C]	293,14	[K]
Boltzmann constant	k <sub>B</sub>	1,38E-23	[J/K]		
Approximat constants	k1	0,045			
	k2	5,00E-04			
	k3	0,18			
Pipe diameter		0,1	[m]		
Fluid density		700	[kg/m <sup>3</sup> ]		
Fluid velocity		2	[m/s]		
Reynolds number		280000			
Friction factor		0,0157			
Viscosity		0,5	[mPas]	0,0005	[Pas]
Particle density asphaltene				1200	[kg/m <sup>3</sup> ]
Particle density sand				2300	[kg/m <sup>3</sup> ]
Frictionless velocity	u*	0,089			
Gravity	g	9,81	[m/s <sup>2</sup> ]		
	g+	3,1E-03			

$$\tau_p = \frac{(\rho_p - \rho_l)d^2}{18\mu}$$

$$u_d^+ = k_1 Sc^{-2/3}$$

$$u_d^+ = k_2 (\tau_p^+)^2$$

$$u_d^+ = k_3$$

$$u_d^+ = k_1 Sc^{-2/3} + k_2 (\tau_p^+)^2 + g^+ \tau_{p-l}^+$$



# References

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