Compaction and Soil Type Effects on Gas Diffusivity and Air Permeability in Vadose Zone Profiles

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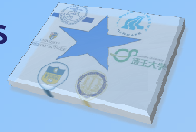
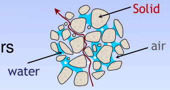


INTRODUCTION

- Accurate prediction of gas diffusivity (D_p/D_o) and air permeability (k_a) as a function of air-filled porosity (ε) in soil is critical for simulating subsurface migration and emission of climate gases and organic vapors.



- Soil type/texture and soil compaction are two important parameters controlling gas movement in soils.
- This study investigates the effects of soil type and compaction on gas diffusivity and air permeability in vadose zone profiles across Denmark, including soils from urban, agricultural, and forest soil sites as well as a final landfill cover soil.
- Compaction-corrected model approaches are presented for both D_p/D_o and k_a, with the models being applicable across different soil types and bulk densities within the range of soil-water matric potential mostly occurring at natural field conditions (between -10 and -500 cm H_2O).

SOIL AND DATA

Urban Soils:

- Hjørring (4-5 and 6-7m depths)
  [Data from Moldrup et al.,2000a (Soil Sci. Soc. Am. J. 64:94-100) and this study]
- Skellingsted (from a final landfill cover, 70cm-depth)
  [Data from Poulsen et al.,2001 (J. Environ.Eng. 127: 145-153)]

Forest Soils:

- Poulstup (10-15 cm and 15-20 cm depths)
  [Data from Moldrup et al., 1996 (Soil Sci. 161:366-375) and Kruse et al., 1996 (Soil Sci. 161:355-365)]

Agricultural Soils:

- Rønhave, Foulum and Jyndevad (lysimeter soils)
- Mammen and Gjorslev (agricultural field soils)

[Data from Kawamoto et al.,2006a (VZJ. 5:1194-1204) and 2006b(VZJ. 5:1205-1215)]

- Ballum,Højer and Korntved (agricultural field soils) (for independent model tests)
  [Data from Schjønning and Rasmussen, 2000 (Soil & Tillage Res. 57: 69-82)]

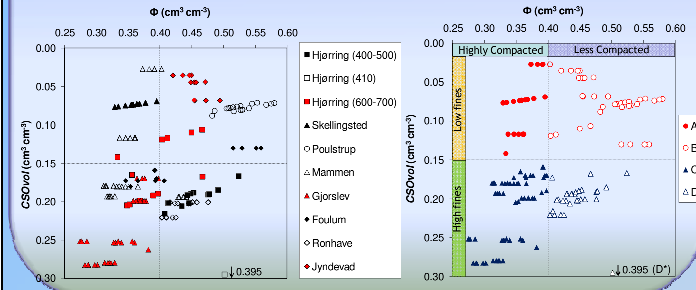
Soil and Data Regrouping

- Regrouped based on **compaction** (total porosity, Φ) and **soil type** (*CSOvol*)

$$CSOvol = \rho_b\left[(clay+silt)/2.7+OM/1\right]$$

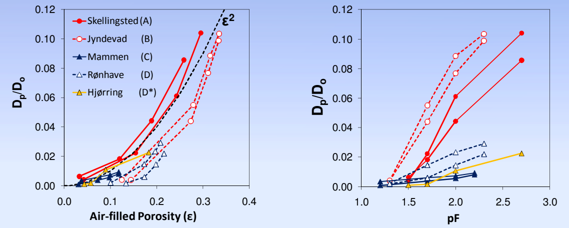
CSOvol = Volume-based fraction of clay, silt and organic matter ($cm^3\,cm^{-3}$) ρ_b = Bulk density ($g\,cm^{-3}$)

Clay, silt, OM = Gravimetric contents of clay, silt, and organic matter ($g\,g^{-1}$)

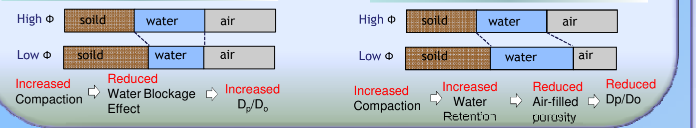


RESULTS AND MODEL DEVELOPMENT

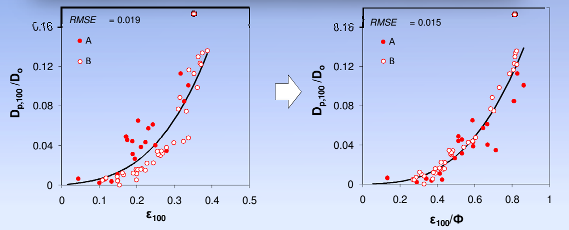
- Compaction and Soil Type



- At given ε,
- At given pF,



Compaction-Corrected Gas Diffusivity Model



- Macroporosity-Dependant (MP) relation

$$D_{p,100}/D_o = 2\varepsilon_{100}^3 + 0.04\varepsilon_{100}$$

- Compaction-Corrected (C-C) MP relation

$$D_{p,100}/D_o = 0.1\left[2(\varepsilon_{100}/\Phi)^3 + 0.04(\varepsilon_{100}/\Phi)\right]$$

- Generalizing,

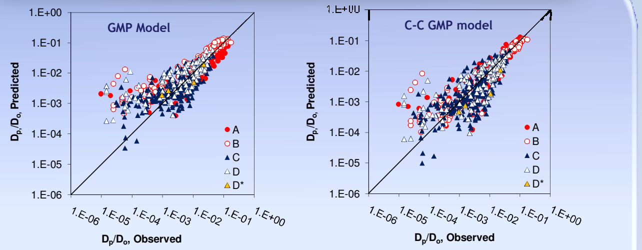
Generalized MP (GMP) Model

$$D_p/D_o = 2\varepsilon^3 + 0.04\varepsilon$$

C-C GMP Model

$$D_p/D_o = 0.1\left[2(\varepsilon/\Phi)^3 + 0.04(\varepsilon/\Phi)\right]$$

Test of Gas Diffusivity Models



Model	Equation	RMSE$_{log}$					BIAS$_{log}$				
		A	B	C	D	Overall	A	B	C	D	Overall
Buckingham (1904)	$D_p/D_o = \varepsilon^2$	0.61	0.66	0.57	0.72	0.63	0.193	0.481	0.118	0.430	0.297
MQ (1960)	$D_p/D_o = \varepsilon^2/\Phi^{2/3}$	0.76	0.81	0.68	0.88	0.77	0.488	0.680	0.435	0.665	0.560
MQ (1961)	$D_p/D_o = \varepsilon^{10/3}/\Phi^2$	0.69	0.49	0.95	0.76	0.77	-0.130	0.016	-0.657	-0.218	-0.306
WLR- Marshall	$D_p/D_o = \varepsilon^{1.5}(\varepsilon/\Phi)$	0.61	0.55	0.60	0.66	0.59	0.183	0.381	-0.052	0.275	0.170
GMP	$D_p/D_o = 2\varepsilon^3 + 0.04\varepsilon$	0.58	0.60	0.50	0.66	0.57	0.047	0.374	0.121	0.294	0.220
C-C GMP	$D_p/D_o = 0.1\left[2(\varepsilon/\Phi)^3 + 0.04(\varepsilon/\Phi)\right]$	0.53	0.40	0.50	0.56	0.49	0.057	0.072	-0.092	0.026	-0.001

Compaction-Corrected k_a Model

- Power-law Model: $k_a = k_{a,100}(\varepsilon/\varepsilon_{100})^{\eta}$

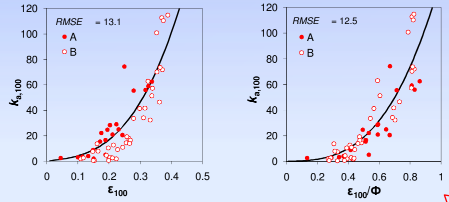
- MP relation

$$k_{a,100} = 700(2\varepsilon_{100}^3 + 0.04\varepsilon_{100})$$

(Kawamoto et al. (2006b)

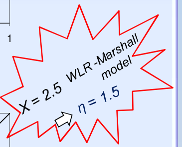
- C-C MP relation

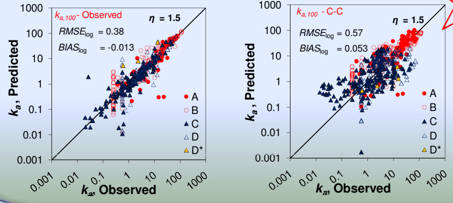
$$k_{a,100} = 70\left[2(\varepsilon_{100}/\Phi)^3 + 0.04(\varepsilon_{100}/\Phi)\right]$$



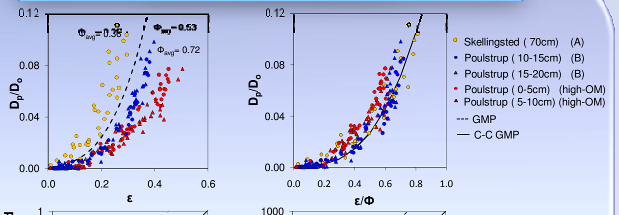
Kawamoto et al. (2006b)suggested

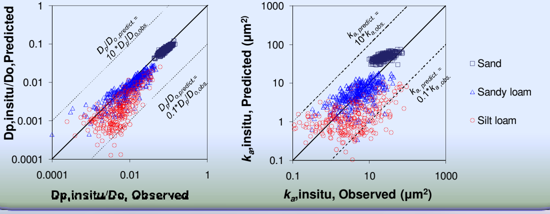
$$\eta = X\text{-}1 \quad where \quad D_p/D_o = \Phi^{T}(\varepsilon/\Phi)^{X}$$





Independent Model Tests





CONCLUSIONS & PERSPECTIVES

- Significant effect of soil compaction on gas transport parameters was observed with a less marked effect of soil type.
- Two compaction-corrected (C-C) models for gas diffusivity and air permeability were introduced which perform well across different soil types and compaction levels.
- In perspective, C-C model approach is to be extended for bimodal/structured soils.

Acknowledgement:

This study was made possible by the project Gas Diffusivity in Intact Unsaturated Soil (“GADIUS”) and the large framework project Soil Infrastructure, Interfaces, and Translocation Processes in Inner Space (“Soil-it-is”), both from the Danish Research Council for Technology and Production Sciences. We gratefully acknowledge the assistance of Innovative Research Organization of Saitama University, Japan.