AD FALCON API Manual

Permeability Models

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1 Permeability Models

FALCON incorporates several permeability models to characterize the flow behavior in unsaturated soils. These models are implemented in distinct classes and are used to compute the intrinsic and relative permeabilities for both water and gas.

1.1 Syntax

Permeability is assigned per material inside the `% Materials` section using `@Perm:` (and optionally `@AnisotropicPerm:`).

```
% Materials
MyMaterial
@Perm: <ModelName> <key1> <value1> <key2> <value2> ...
@AnisotropicPerm: <six coefficients>
%%%
```

Notes:

- Directive lookup is case-insensitive and extra leading `@` characters are accepted (so `@Perm:`, `@@perm:`, and `@@PERM:` are treated the same for selecting the directive).
- A space after `:` is optional (`@Perm:VanGenuchten ...` and `@Perm: VanGenuchten ...` both work).
- Model keywords (the first token after `@Perm:`) and parameter keys should be written exactly as documented on the model page.
- See Material Models: Syntax & Conventions for the shared rules across all material directives.

1.2 Overall Permeability Formula

For each phase, the directional permeability components used in the flow equations follow the same general structure:

$$k_{\alpha,ij}^{\text{eff}} = k_{ij}^{\text{aniso}}\ k_{sat}\ k_{r\alpha}(S_e, e)\ /\ \mu_\alpha$$

where:

- α is the phase (`w` for water, `g` for gas/air) and μ_α is the phase viscosity.
- k_{sat} is the saturated permeability provided by the selected `@Perm:` model.
- k_{ij}^{aniso} is the anisotropy coefficient from `@AnisotropicPerm:` that scales the base `k_sat` by direction/coupling. If `@AnisotropicPerm:` is not provided, isotropic behavior is assumed (effectively $k_{ij}^{\text{aniso}} = 1$ for the active components).
- $k_{r\alpha}(S_e, e)$ is a dimensionless multiplier from the selected `@Perm:` model:
  - saturation-dependent models provide $k_r(S_e)$,

- some models also incorporate void ratio effects (either directly or through an explicit $k_e(e)$ multiplier).

1.3 Available Models

In input files, the model keyword is the first token after `@Perm:` (shown below in monospace).

1. `Constant` — fixed permeability (see Constant Permeability)
2. `VoidRatioAffectedConstant` — void-ratio-scaled constant model (see Void Ratio Affected Constant Permeability)
3. `VanGenuchten` — saturation-dependent $k_r(S_e)$ (optional void-ratio scaling via `e_ref`) (see van Genuchten)
4. `BrooksCorey` — saturation-dependent $k_r(S_e)$ (optional void-ratio scaling via `e_ref`) (see Brooks-Corey)
5. `VanGenuchtenKe` / `BrooksCoreyKe` — explicit $k_e(e)\,k_r(S_e)$ multiplier form (see k_e Multiplier)

Each model provides different approaches to capturing the hydraulic behavior of soils under various saturation and void ratio conditions.

1.4 Example Inputs (and what they mean)

These lines are typically written inside a material block (for example, within `% Materials`).

1.4.1 Example 1: Saturated / constant permeability (no saturation or void-ratio effects)

```
@Perm: Constant k_sat 1e-10
```

Interpretation:

- Sets the saturated permeability to `1e-10` (units consistent with your model).
- Uses `k_rw = 1` and `k_rg = 0` from the permeability model (so gas flow is not represented by this model).
- If you also specify `@AnisotropicPerm:`, those directional factors scale the permeability via the overall formula in this page.

1.4.2 Example 2: Unsaturated Van Genuchten (with optional void-ratio scaling via `e_ref`)

```
@Perm: VanGenuchten m 0.9 k_sat 1e-10 e_ref 0.6
```

Interpretation:

- `m` controls the shape of the saturation-dependent relative permeabilities $k_{rw}(S_e)$ and $k_{rg}(S_e)$.

- `k_sat` is the saturated permeability scale.
- `e_ref` enables void-ratio scaling of the relative permeability multipliers (if `e_ref > 0` and the current void ratio `e > 0`).
- In fully coupled analyses, both water and gas multipliers are used (k_{rw} and k_{rg}).

1.4.3 Example 3: Unsaturated Van Genuchten with explicit $k_e(e)\,k_r(S_e)$ form

```
@Perm: VanGenuchtenKe m 0.9 k_sat 1e-10 ke_ref 0.6 k_min 1e-6
```

Interpretation:

- Computes a saturation-dependent multiplier $k_r(S_e)$ (Van Genuchten), then scales it by a void-ratio multiplier $k_e(e)$.
- `ke_ref` is the reference void ratio used in $k_e(e)$ (you can also write `e_ref` as a synonym).
- `k_min` is a lower bound on the final multiplier $\max(k_e\,k_r,\ k_{min})$ to avoid numerically-zero conductivities.

1.4.4 Example 4: Unsaturated Brooks–Corey with explicit $k_e(e)\,k_r(S_e)$ form

```
@Perm: BrooksCoreyKe lambda 0.7 k_sat 5e-11 ke_ref 0.8 k_min 1e-6
```

Interpretation:

- Uses Brooks–Corey formulas for $k_{rw}(S_e)$ and $k_{rg}(S_e)$ and then multiplies by $k_e(e)$.
- `lambda` controls the saturation sensitivity.
- `k_sat`, `ke_ref`, and `k_min` play the same roles as in `VanGenuchtenKe`.

1.4.5 Example 5: Adding anisotropy and viscosity (how the full formula is assembled)

```
@AnisotropicPerm: 1 2 1 0 0 0
@PhaseChar: Liquid rhow 1000 l_vicosity 1e-3 K_l 2.2e9
@PhaseChar: Gas    rhog 1.2  g_vicosity 1.8e-5 k_g 1.4e5
@Perm: VanGenuchtenKe m 0.9 k_sat 1e-10 ke_ref 0.6
```

Interpretation:

- `@AnisotropicPerm:` provides the directional scaling coefficients k_{ij}^{aniso} applied to the base `k_sat`.
- `@Perm:` provides the scalar `k_sat` and the dimensionless multiplier $k_{r\alpha}(S_e, e)$.
- `@PhaseChar:` provides the phase viscosities μ_w and μ_g used in the division.