**Appendix 1**

1. **Permeate Flux (J,** (L/m²·h)**:** Flux or permeation rate, is the quantity (volume) flowing through the membrane per unit area and time. **The basic equation for solvent flow through a membrane is, J =** $Q/A$ **w**here, J is the permeate flux; Q is the permeate volumetric flow rate (L/h or m³/s) and A is the membrane surface area (m²). **In pressure-driven membranes (e. g., UF, NF, RO), flux is also given by, J = Lp X (ΔP − Δπ)** where, Lp​ is the membrane permeability (L/m²·h·bar); ΔP is the transmembrane pressure (TMP) (bar or Pa) and Δπ is the osmotic pressure difference across membrane.
2. **Solute Penetration (P):** penetration of a membrane is the solute transport through the membrane, which is related to membrane permeability and selectivity. Penetration refers to the extent solutes pass through the membrane, influenced by membrane pore size, solute size, and operating conditions. **Penetration is the inverse of rejection: P = Cp/Cf  w**here, P is the solute penetration (fraction, often <1); Cp​ is the solute concentration in the **permeate** [e.g., mg/L] and Cf​ is the solute concentration in the **feed** [e.g., mg/L]. Alternatively, **solute rejection** R is: R = (1 − Cp/Cf​​) × 100% where, R is the solute rejection (%); Cp is the solute concentration in permeate and Cf​ is the solute concentration in feed.
3. **Separation Efficiency (η):** Efficiency is defined as the rejection rate or separation factor, related to the ratio of solute concentration in permeate to feed. Thus,

η = (amount retained / total amount in feed) × 100 %

Membrane Separation Efficiency is a performance metric that quantifies how effectively a membrane separates a solute from a solvent. It is typically assessed using rejection, selectivity, or separation factor, depending on the process (liquid or gas separation).

1. **Separation Factor (Gas or Multi-Solute Systems):** This indicates how preferentially a membrane allows component A to pass over B. For gas separations or multi-component systems, separation factor (α) is used:

α A/B = (yA/yB) / (xA/xB)

where, αA/B is the separation factor of component A over B, y is the mole fraction in the **permeate** and x is mole fraction in the **feed**.

**References:**

1. Shaffer, D. L., et al. Desalination and Reuse of High-Salinity Shale Gas Produced Water: Membrane Treatment and Cost Evaluation. Environmental Science & Technology, 2015, 49(1), 130 - 139, Doi: 10.1021/es504241p.
2. Madaeni, S. S., The application of membrane technology for water disinfection, Water Research, 1999, 33(2), 301–308. [Doi: 10.1016/S0043-1354(98)00207-9](https://doi.org/10.1016/S0043-1354%2898%2900207-9).
3. Mulder, M., Basic Principles of Membrane Technology. 2nd Edition. Springer, Chapter 2 and Chapter 5 cover flux equations and transport mechanisms,1996,
Doi: 10.1007/978-94-009-1766-8.
4. Elimelech, M., et al., Reverse osmosis desalination: Water sources, technology, and today's challenges, Environmental Science & Technology, 1996, 36(12), 252A - 258A. [Doi: 10.1021/es0129703](https://doi.org/10.1021/es0129703).
5. Song, L., & Elimelech, M., Theory of concentration polarization in crossflow filtration, Journal of the Chemical Society, Faraday Transactions, 1995, 91(19), 3389 – 3398,
[Doi: 10.1039/FT9959103389](https://doi.org/10.1039/FT9959103389).
6. Wijmans, J. G., & Baker, R. W., The solution-diffusion model: a review, Journal of Membrane Science,1995, 107(1 - 2), 1 - 21, Doi: 10.1016/0376-7388(95)00102-I.