The second term in Eq. 2 is the contribution of non-electrostatic (excluded volume) interactions accounted for the mobile ions volume as well

$$F_{\text{int}} = \frac{N}{\varphi}\left[(1-\varphi-\varphi_+-\varphi_-)\ln(1-\varphi-\varphi_+-\varphi_-)+\chi\varphi(1-\varphi-\varphi_+-\varphi_-)\right], \tag{4}$$

where the first term is the entropy of solvent molecules and the second is the energy of volume interactions defined by the Flory-Huggins parameter χ. The value $\chi = 0$ corresponds to athermal solvent, $\chi = 0.5$ – the theta-solvent and $\chi > 0.5$ corresponds to a poor solvent.

The third term in Eq. 2 accounts for ionic contributions: the translational entropy of mobile ions and for their partial pressure inside and outside the gel

$$F_{\text{ion}} = \frac{2c_{\text{s}}N}{\varphi}\left[1-\sqrt{1+\left(\frac{\alpha\varphi}{2c_{\text{s}}}\right)^2}\right]+N\ln(1-\alpha) \tag{5}$$

where ionization degree, α, is calculated based on local ionization equilibrium and the local electroneutrality condition from the following equation

$$\frac{\alpha}{1-\alpha}10^{\text{p}K-\text{pH}} = \sqrt{1+\left(\frac{\alpha\varphi}{2c_{\text{s}}}\right)^2}-\frac{\alpha\varphi}{2c_{\text{s}}} \tag{6}$$

The derivation of the last two equations can be found in [2, 3].

Thus, taking a derivative of the hydrogel free energy Eq. 2 with respect to the gel volume, one could obtain the hydrogel partial pressure p or other words, the pressure needed to be applied to the hydrogel using a semipermeable sieve in order to make gel density equal to φ

$$p(\varphi,\ c_{\text{s}}) = -\left(\frac{\partial F(\varphi(V_{\text{gel}}),\ c_{\text{s}})}{\partial V_{\text{gel}}}\right)_{c_{\text{s}}} \tag{7}$$

Because we assume all term of free energy independent we can work on them separately as following

$$p(\varphi,\ c_{\text{s}}) = -\left(\frac{dF_{\text{conf}}}{dV}+\frac{dF_{\text{int}}}{dV}+\frac{dF_{\text{ion}}}{dV}\right) \tag{8}$$

$$\frac{dF_{\text{conf}}}{dV} = \frac{A^{2/3}N^{d-1}\left(1-d\dfrac{1-\dfrac{(AN/\varphi)^{2/3}}{b^2N}}{N-(AN/\varphi)^{2/3}}\right)}{(N/\varphi)^{1/3}\left(N-(AN/\varphi)^{2/3}\right)^d}-\frac{\varphi}{N} \tag{9}$$

$$\frac{dF_{\text{int}}}{dV} = \left(1-\frac{c_{\text{s}}}{\xi}-c_{\text{s}}\xi\right)\ln\left(1-\varphi-\frac{c_{\text{s}}}{\xi}-c_{\text{s}}\xi\right)+\varphi+\chi\varphi^2+\frac{\left(\dfrac{c_{\text{s}}}{\xi}-c_{\text{s}}\xi\right)\left[\ln\left(1-\varphi-\dfrac{c_{\text{s}}}{\xi}-c_{\text{s}}\xi\right)+\varphi+\chi\varphi^2\right]}{(2-\alpha)\,\alpha\varphi+\dfrac{2c_{\text{s}}\xi}{\alpha}}, \tag{10}$$

where $\xi = \dfrac{\alpha\,(1-\alpha_{\text{b}})}{\alpha_{\text{b}}\,(1-\alpha)} = \sqrt{1+\left(\dfrac{\alpha\varphi}{2c_{\text{s}}}\right)^2}-\dfrac{\alpha\varphi}{2c_{\text{s}}}$

$$\frac{dF_{\text{ion}}}{dV} = -2c_{\text{s}}\left(\sqrt{1+\left(\frac{\alpha\varphi}{2c_{\text{s}}}\right)^2}-1\right) \tag{11}$$