

Magnetic separation assisted liquid-liquid rare earth solvent extraction

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The Kelvin force has a long history of being applied in separating particles with contrasting electromagnetic properties. In the past decades, a surprising effect of the Kelvin force on a local formation of enrichment of paramagnetic ions, despite the presence of a dominating thermal energy, has been repeatedly reported [1-4]. This phenomenon inspires a magnetic separation technique of rare earth (RE) ions. Since the chemical similarity of the rare earth forces a large number of time-consuming extraction steps, efficiently exploited differences in the magnetic moments of the rare earth ions could speed up the process significantly. However, the application of such a magnetic separation step requires a sufficient understanding of the above-mentioned observations.

Due to the huge difference in the order of magnitude between the kinetic energy and the magnetic energy, it actually seems unlikely that Kelvin force has a direct influence on the formation of localized paramagnetic ions, i.e. enrichment. In fact, an external source of a concentration gradient, e.g. evaporation, is needed. Evaporation gives rise to local enrichment at the interface by losing water molecules across the interface. Generally, the evaporation-driven concentration boundary layer is hydrodynamically unstable, because it is heavier than the underlying bulk fluid. It is the field gradient force, acting in the opposite direction to gravity, which suppresses the resulting Rayleigh-Taylor instability. We showed that [2-3] the gravitational force acting on the boundary layer, expressed in a non-dimensional manner by the Rayleigh number, is drastically diminished by the approximately five times larger Kelvin force. Therefore, the velocity field is modified with the presence of magnet which further leads to a localization of paramagnetic rare earth ions in the vicinity of the magnet. To deploy magnetic separation in the mixed rare earth ions, alternative

reagent could be added which offers selective affinity, though limited, towards different rare earth ions.

In view of industrial scale rare earth separation, solvent-solvent extraction is the widely adopted technology. It works on the principle of differing affinity of rare earth with ligand and is realized in form of emulsion by mixing the immiscible organic phase with aqueous phase. Due to the limited separation factor, repeating cascade stages with counter-current flow direction for organic and aqueous phase including large amount of chemicals which are partially not recyclable is typically mandatory. By applying Kelvin force into this liquid-liquid system, we are working on accelerating the equilibrium formation time while reducing the required ligand by manipulating the flow field inside the aqueous phase which concentration inhomogeneity is generated by the selective cation exchange between the ligand and rare earth trivalent ions. This is potentially a route for recycling Nd(III) from end-of-life permanent magnet.

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