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ANALYSIS OF REY BEHAVIOR IN THE COAL COMBUSTION PROCESS

Coal is recognized as a valuable source for the recovery of Rare Earth Elements and Yttrium (REY) – a group comprising the 15 lanthanides (La–Lu) as well as scandium (Sc) and yttrium (Y), which share similar chemical properties. These metals are in high demand across various industrial sectors, including the production of batteries, lightweight alloys, magnets, medical equipment, and electronics. Of particular interest are the so-called critical REY (Nd, Eu, Tb, Dy, Y, Er), which relative abundance may vary depending on the origin and characteristics of a given coal.

Traditionally, REY are produced via mining of primary deposits (e.g., monazite, xenotime, bastnaesite). However, such methods often carry high costs and significant environmental risks, leading to increased interest in alternative (secondary) sources, among which coal ash has emerged as particularly important [1].

In coal, REY can occur in both organically bound forms (notably in low-rank coals, such as lignites, where organically associated REY may reach 50%) and in mineral phases (phosphates, carbonates, sulfates, zircon, apatite, etc.). In high-rank coals, mineral forms of REY prevail [2].

At typical coal combustion temperatures, REY do not substantially volatilize; instead, they partition among various ash fractions, primarily fly ash and bottom ash. Studies indicate that fly ash can contain between 42% and 94% of the total REY present in coal combustion products. Within coal ash, REY may persist in residual minerals (monazite, xenotime, aluminosilicates), be incorporated into amorphous glassy phases, or be present as fine particles and adsorbed species on the ash surface. In contrast, the concentrations of REY in flue gas or desulfurization by-products (e.g., FGD gypsum) typically do not exceed 1% [3].

Figure 1 illustrates the general behavior of REY during successive stages of coal combustion. As coal particles are heated, they may either remain largely intact or undergo fragmentation into smaller particles. During this process, melting and coalescence of particles take place, forming liquid droplets. Organically bound REY may partially transition to the vapor phase (REY vapor). At high temperatures, some REY remain within their original mineral inclusions, while another portion vaporizes and subsequently condenses upon cooling. Nucleation, coagulation, and agglomeration processes then lead to the formation of fine ash aerosols. The combustion process concludes with a cooling phase, during which liquid droplets containing REY solidify.

Thus, the following final products emerge from coal combustion:

- Cenospheres (hollow spherical ash particles);
- Glassy particles containing REY;
- Micron-scale REY grains, encapsulated within a glassy matrix;
- Dispersed ash aerosols, representing the finest fraction of the ash stream.

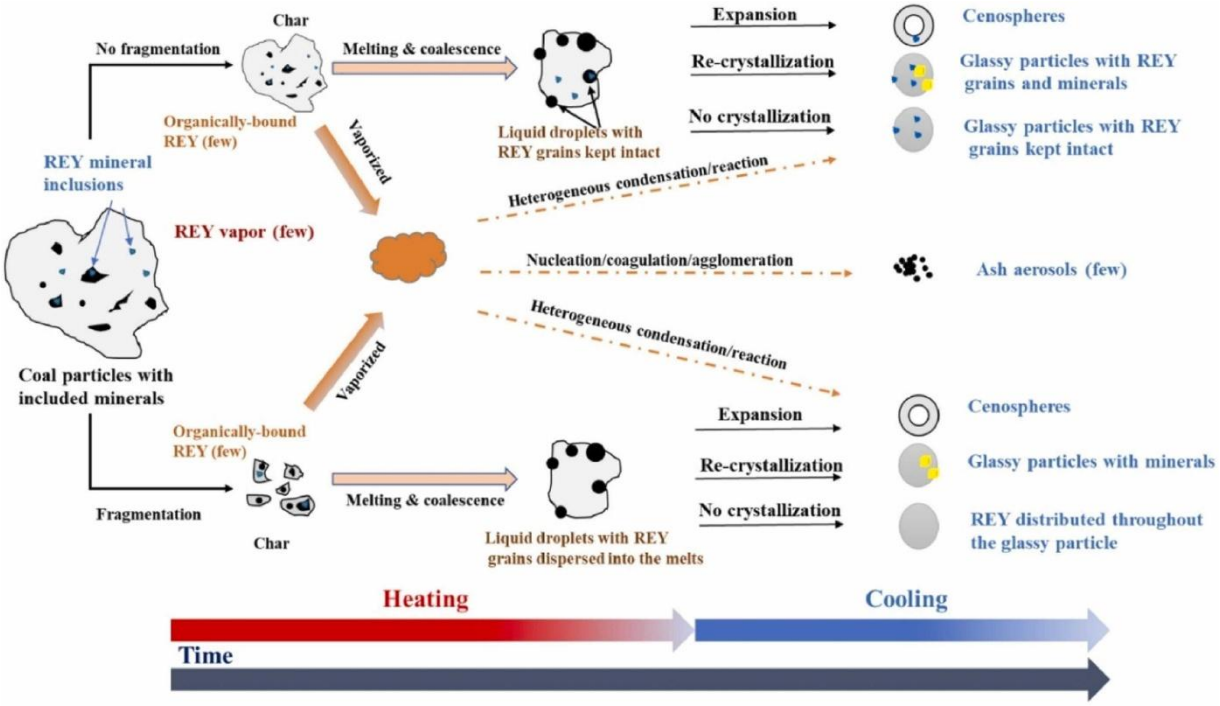

Figure 1 – Schematic representation of REY behavior during different stages of coal combustion [4]

Although coal ash is now considered a promising source for REY recovery, helping reduce reliance on traditional mining and addressing some environmental issues related to coal waste, the effect of combustion parameters on REY distribution is still not fully understood and requires further research. Identifying and optimizing these factors could significantly improve the efficiency of REY extraction technologies from coal ash, as well as enable more accurate predictions of processing outcomes.

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