Comparative Characterization of LMF, BOF, and EAF Steel Slags for Thermal Energy Storage (TES) for Concentrated Solar Power (CSP).

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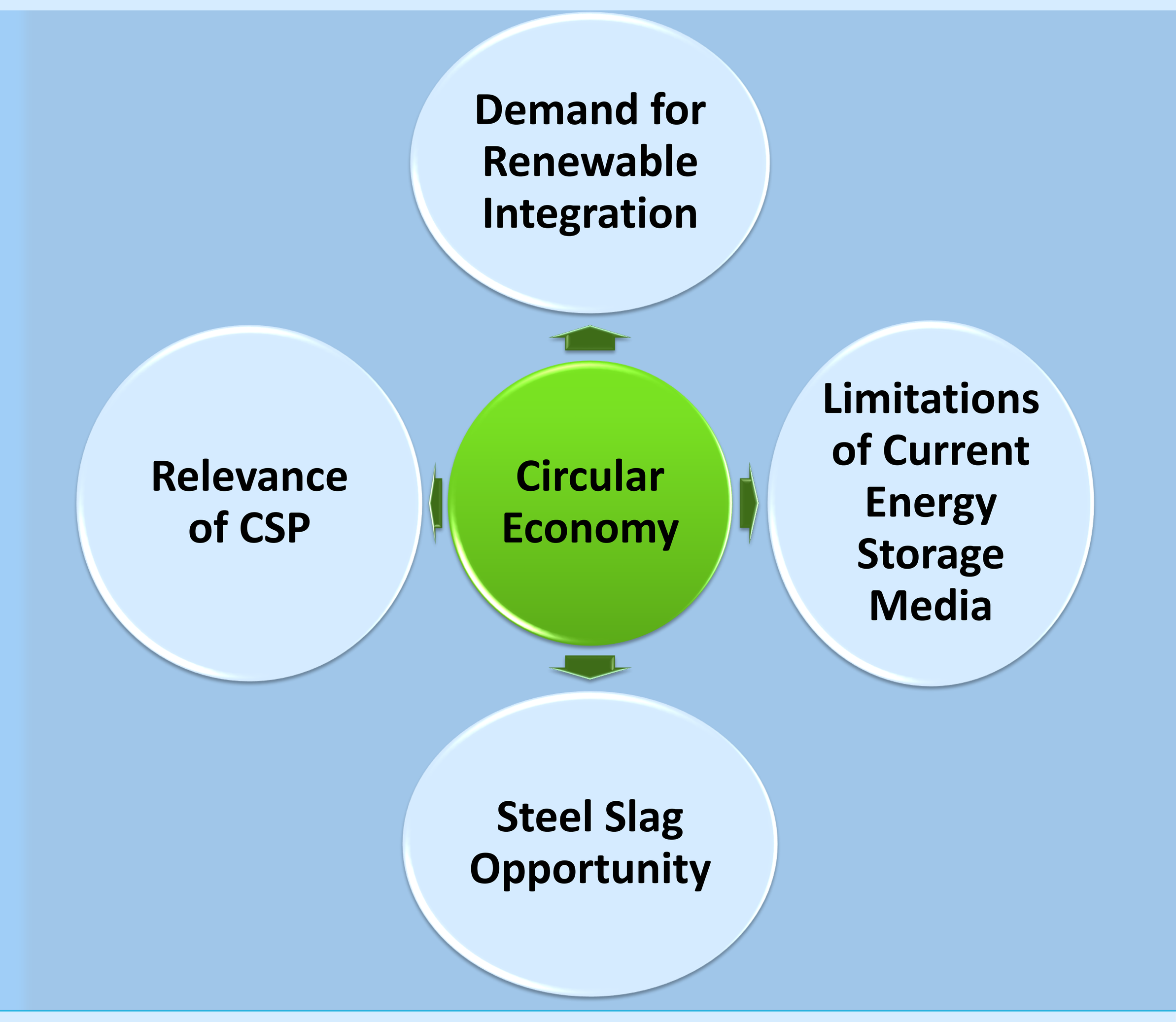
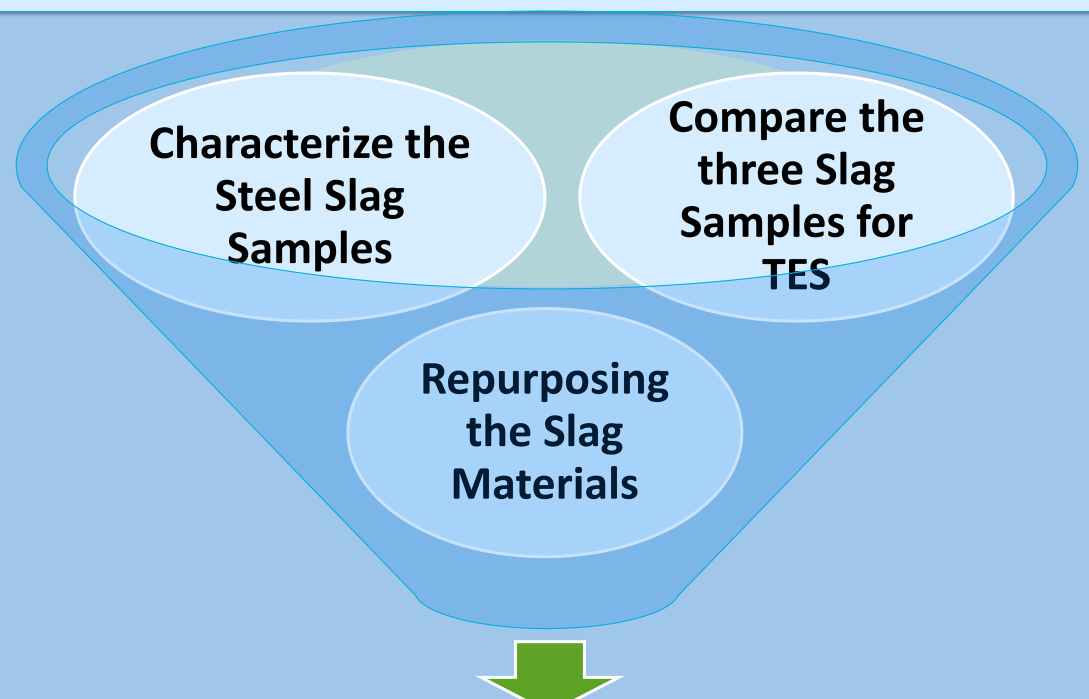
Introduction/Background



Objectives/Hypothesis



Steel Slags as low-cost, sustainable, and efficient alternatives to conventional TES materials in CSP systems

Methods

- **Sample Preparation**: The slag samples were oven-dried at 105 °C (overnight), then crushed using a crusher and ball mill to obtain fine powder (<150 µm) suitable for characterization.
- **XRF:** Identify major oxides (CaO, SiO_2, Al_2O_3, MgO) critical for thermal stability and heat storage.
- **XRD:** Determine crystalline phases influencing melting point, stability, and energy retention.
- **SEM–EDS:** Examine surface morphology and elemental distribution affecting heat transfer and durability.
- **FTIR:** Detect bonding features (Si–O, Al–O, Fe–O) linked to structural integrity under heating.
- **TGA:** Assess weight loss and decomposition to confirm slag resilience at high TES operating temperatures.
- **DSC:** Measure endothermic/exothermic behavior and heat capacity for energy storage performance.

Results

XRF Analysis

- Fe_2O_3 (~40%) dominates all slags, with high storage capacity but risk of phase changes.
- BOF is richest in CaO, has stronger high-temperature stability, and sintering resistance.
- EAF higher in MgO/MnO, better conductivity; LMF shows balanced composition.

SEM Morphology

- LMF: Angular, rough particles, high surface area, loose packing.
- BOF: Porous, flaky structure, lower conductivity, good thermal shock resistance.
- EAF: Compact, dense grains, high conductivity/energy density, cracking risk.

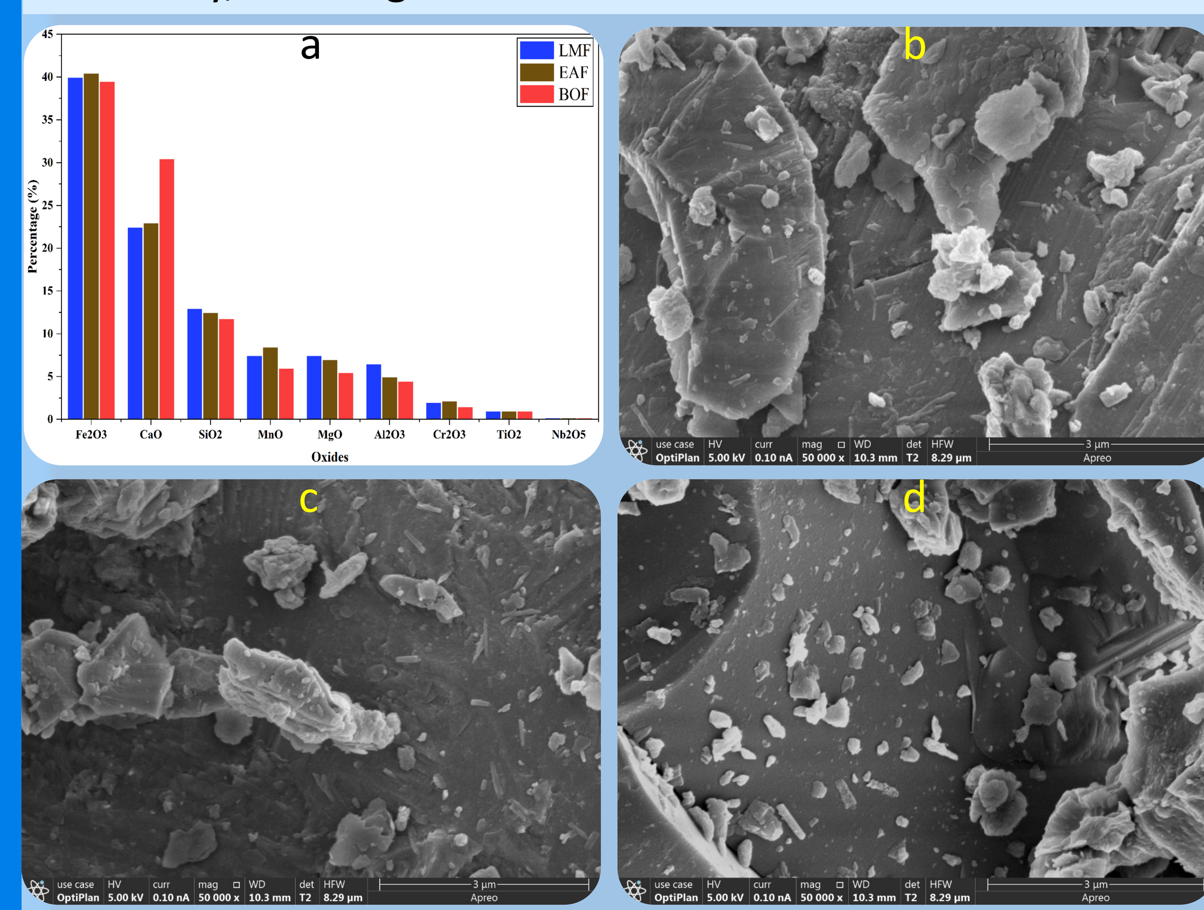


Fig. 1: (a) Comparative oxide composition of the steel slags. SEM Images of (c) LMF, (c) BOF, (d) EAF.

- **EDS:** Ca, Fe, Si dominate; Mg, Al, Mn as secondary oxides; trace Ti, V, Cr.
- **FTIR:** Silicate/aluminate (1000–1100 cm⁻¹), carbonate (1500–1600 cm⁻¹), hydroxyl (3700–3800 cm⁻¹) [1].
- **TES Relevance:** BOF (high CaO, reactive), LMF (balanced), EAF (high Fe oxides, better conductivity).

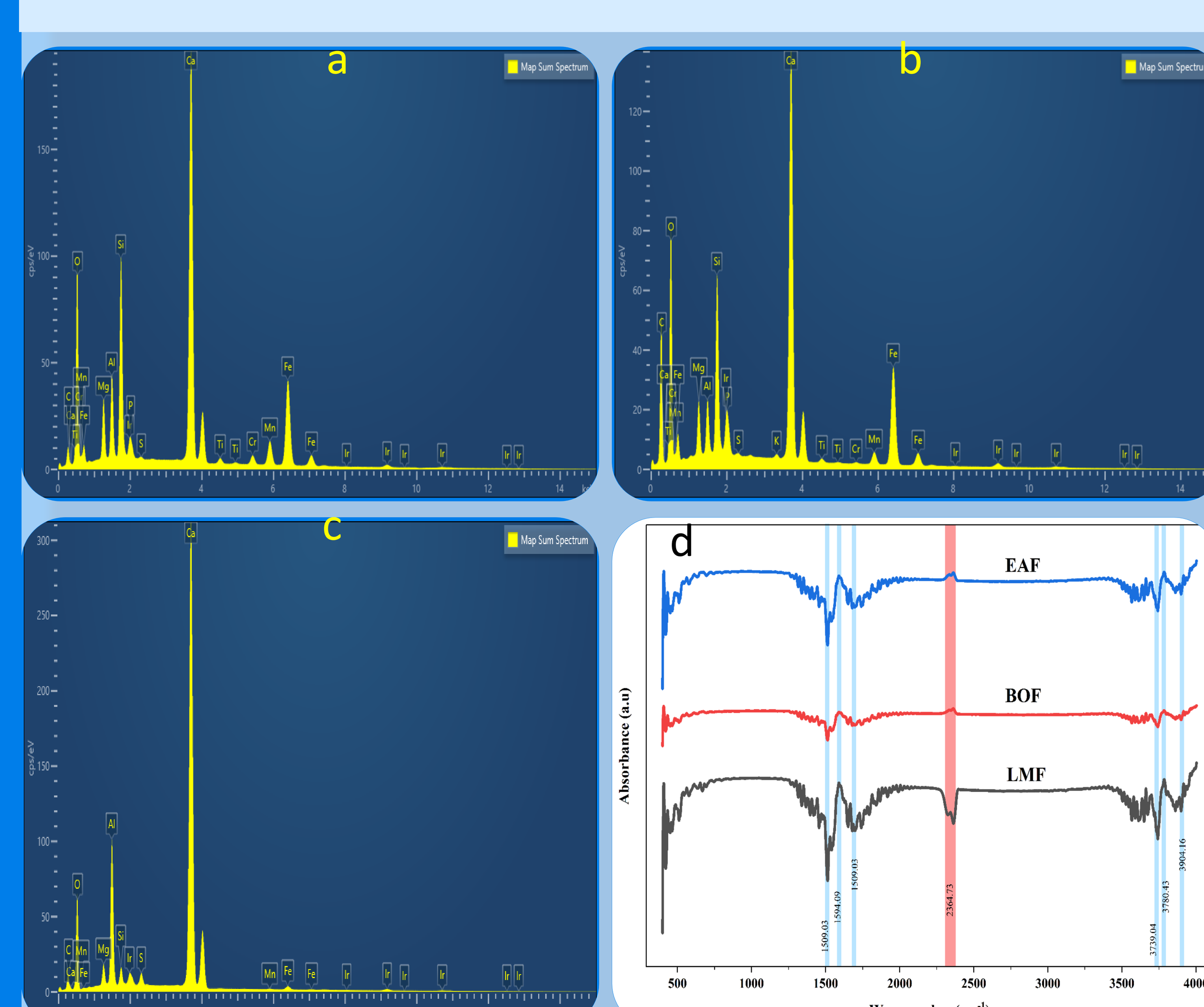


Fig. 2: EDS spectra of (a) EAF, (b) BOF, and (c) LMF steel slags, (d) Stacked FTIR spectra of the slag samples

The variation in crystalline phases explains differences in thermal stability and reactivity. EAF slag is better for conductivity, BOF slag is reactive but less stable, while LMF slag offers a more balanced performance for TES.

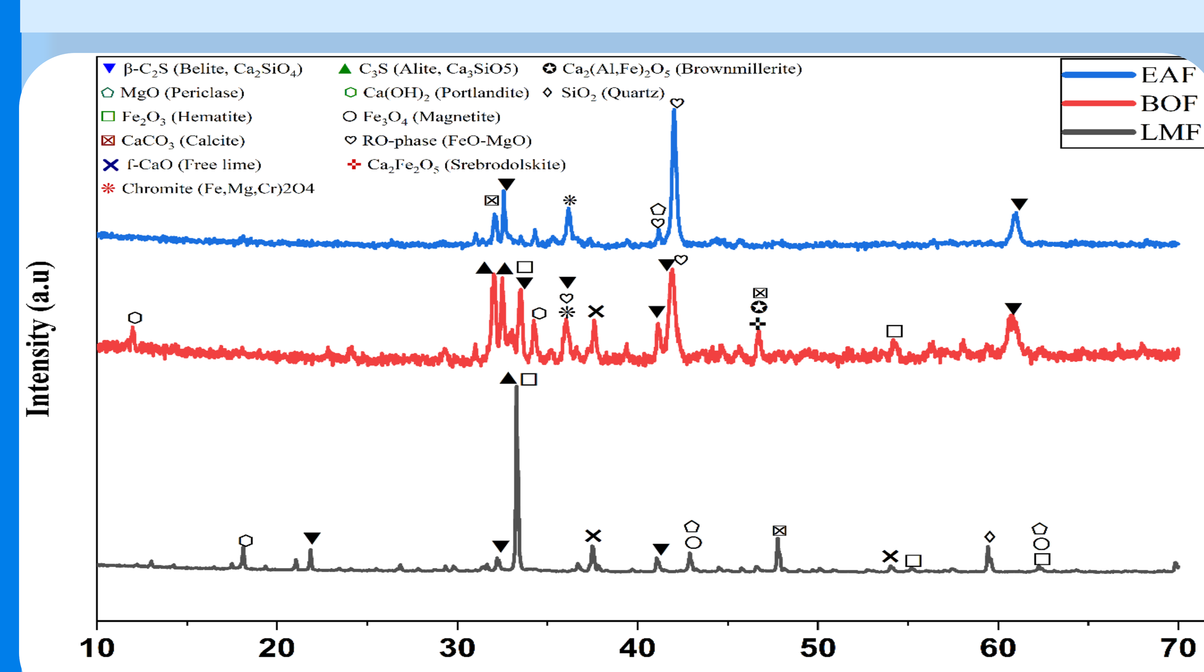


Fig. 3: XRD patterns of EAF, BOF, and LMF slags showing major crystalline phases.

TGA/DTG Analysis

- LMF Shows ~1.7% total weight loss, mainly between 200–450 °C, linked to decomposition of hydrates and minor carbonates [2].
- EAF: Very stable, with <0.5% total loss across 30–800 °C, indicating excellent thermal resistance.
- BOF: Moderate stability, ~1% total loss with multiple small steps, suggesting phase changes and volatile release.

DSC / Heat Flow

- LMF: Highest heat flow, strong potential for energy storage.
- BOF: Lowest heat flow, lower energy density, but stable behavior.
- EAF: Intermediate heat flow, balancing stability and storage performance.

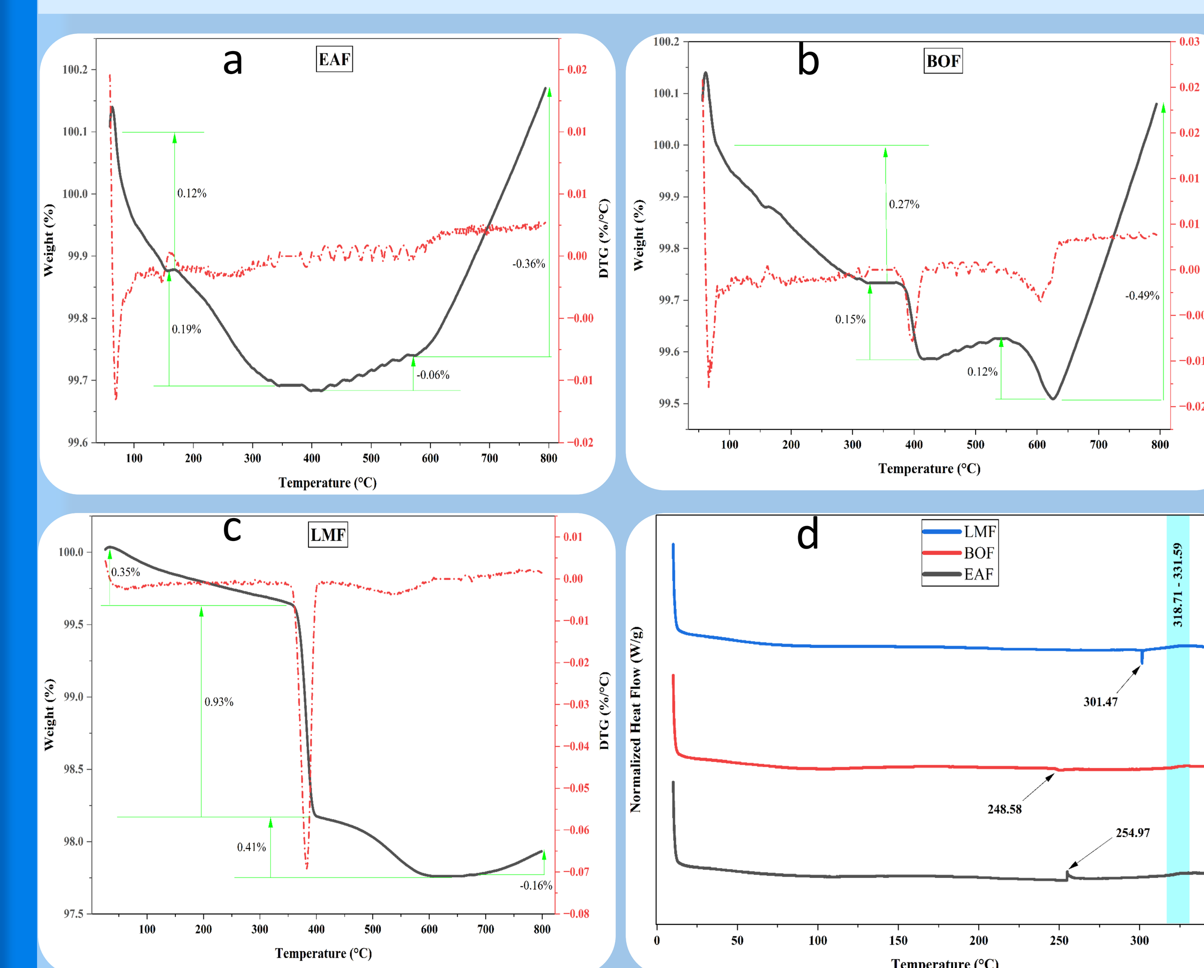


Fig. 4: Thermogravimetric (TGA) curves of (a)EAF, (b)BOF, (c)LMF, and (d) derivative thermogravimetric (DTG) curves of the slags

Conclusion /Discussion

- BOF slag, rich in CaO, shows high reactivity but moderate thermal stability.
- LMF slag demonstrates the highest heat flow with a balanced composition, making it the most promising for efficient energy storage.
- EAF slag, dominated by Fe oxides, exhibits superior thermal stability and enhanced conductivity, supporting long-term cycling performance.

All three slags are oxide-rich, abundant industrial by-products that can be repurposed as cost-effective TES materials, supporting sustainability and the circular economy.

References

1. Wang, X., Ni, W., Li, J., Zhang, S., & Li, K. (2021). Study on mineral compositions of direct carbonated steel slag by QXRD, TG, FTIR, and XPS. *Energies, 14*(15), 4489. https://doi.org/10.3390/en14154489
2. Di, Z., Cao, Y., Yang, F., Cheng, F., & Zhang, K. (2018). Studies on steel slag as an oxygen carrier for chemical looping combustion. *Fuel, 226*, 423–432. https://doi.org/10.1016/j.fuel.2018.04.047

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