Experimental Study of Iron Oxide Electroreduction with Different Cathode Material

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EXPERIMENTAL STUDY OF IRON OXIDE ELECTROREDUCTION WITH DIFFERENT CATHODE MATERIAL

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BACKGROUND

- In the energy transition era, electroreduction of iron oxide can contribute to :
  - **GREEN IRON/STEEL MAKING:** CO_2-free iron/steel production, powered by renewable energy sources. [1]
  - **IRON FUEL CYCLE**: utilization of iron powder as a recyclable and CO_2-free dense energy carrier (Fig. 1). [2]

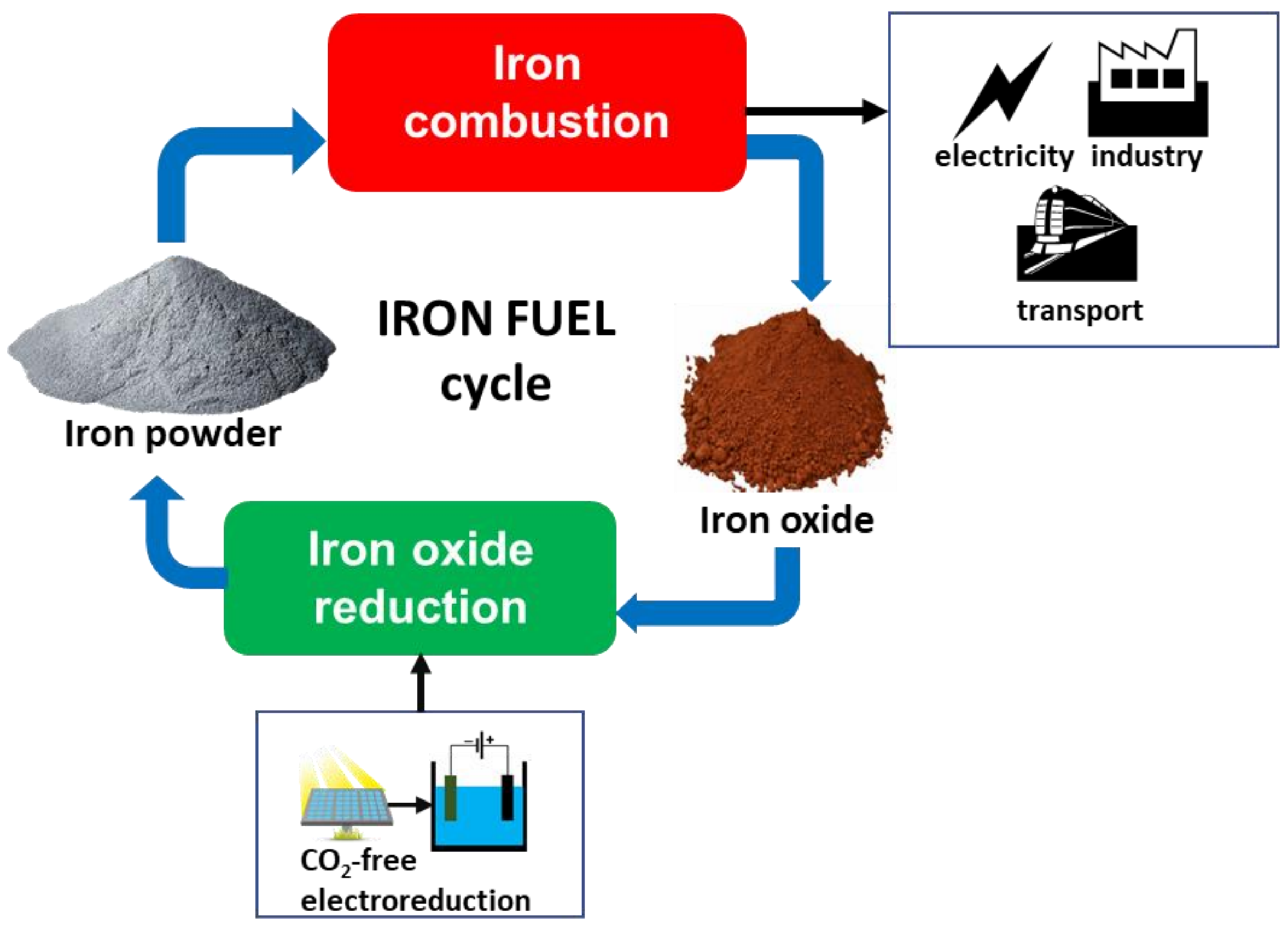

Fig 1. Schematic concept of the iron fuel cycle

Objectives:

- To identify compatibility of cathode material to electroreduction of iron oxide.
- To investigate the electrochemical performance.

EXPERIMENTS

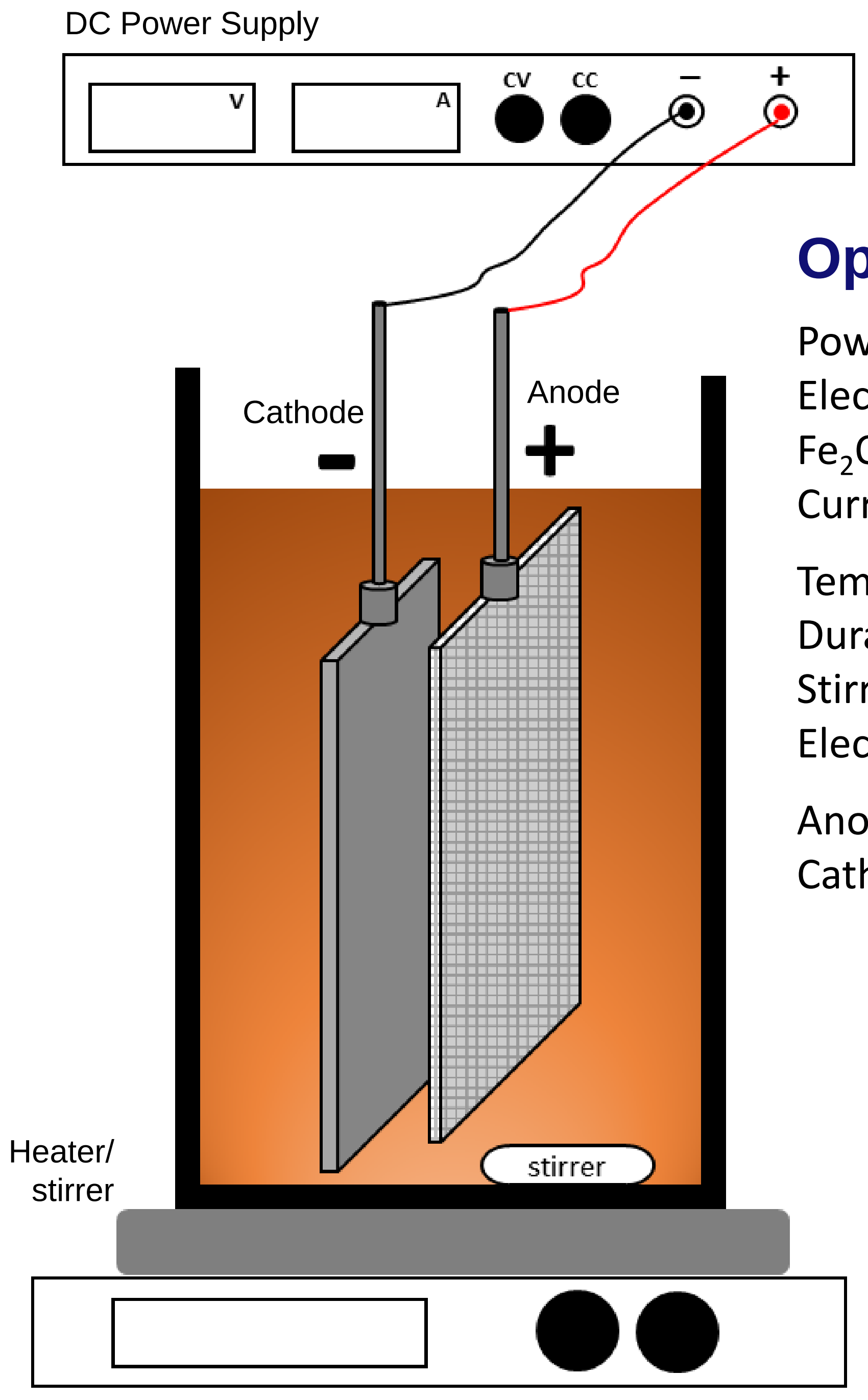

Fig 2. Experimental apparatus

Operating conditions

Powder : Fe_2O_3 powder (size ≤ 5 µm, ≥ 96%)
Electrolyte : NaOH (50 wt%; 18 M)
Fe_2O_3 content (ϕ) : 5 – 20 wt.%
Current density (σ) : 1000 – 4000 A/m^2 (0.6 – 2.4 A)

Temperature : 110 ± 5 °C
Duration : 1 hour (3600 seconds)
Stirring speed : 100 rpm
Electrode gap : ± 15 mm

Anode (CE) : Nickel mesh
Cathode (WE) : Graphite, Stainless Steel, Nickel mesh*
Copper (size: 15 mm x 40 mm x 2 mm)

**Nickel mesh size: 15 mm x 40 mm x 1 mm*

Current efficiency

$$\eta = \frac{m_{real}}{m_{faradaic}} = m_{deposit} \cdot \left(\frac{n \cdot F}{M \cdot I \cdot t}\right)$$

n : number of electrons [3: $Fe^{3+} \rightarrow Fe^0$]
F : Faraday constant [96485 sA/mol]
M : Iron molar mass [55.85 gr/mol]
I : Current supply [A]
t : Duration [s]

RESULTS

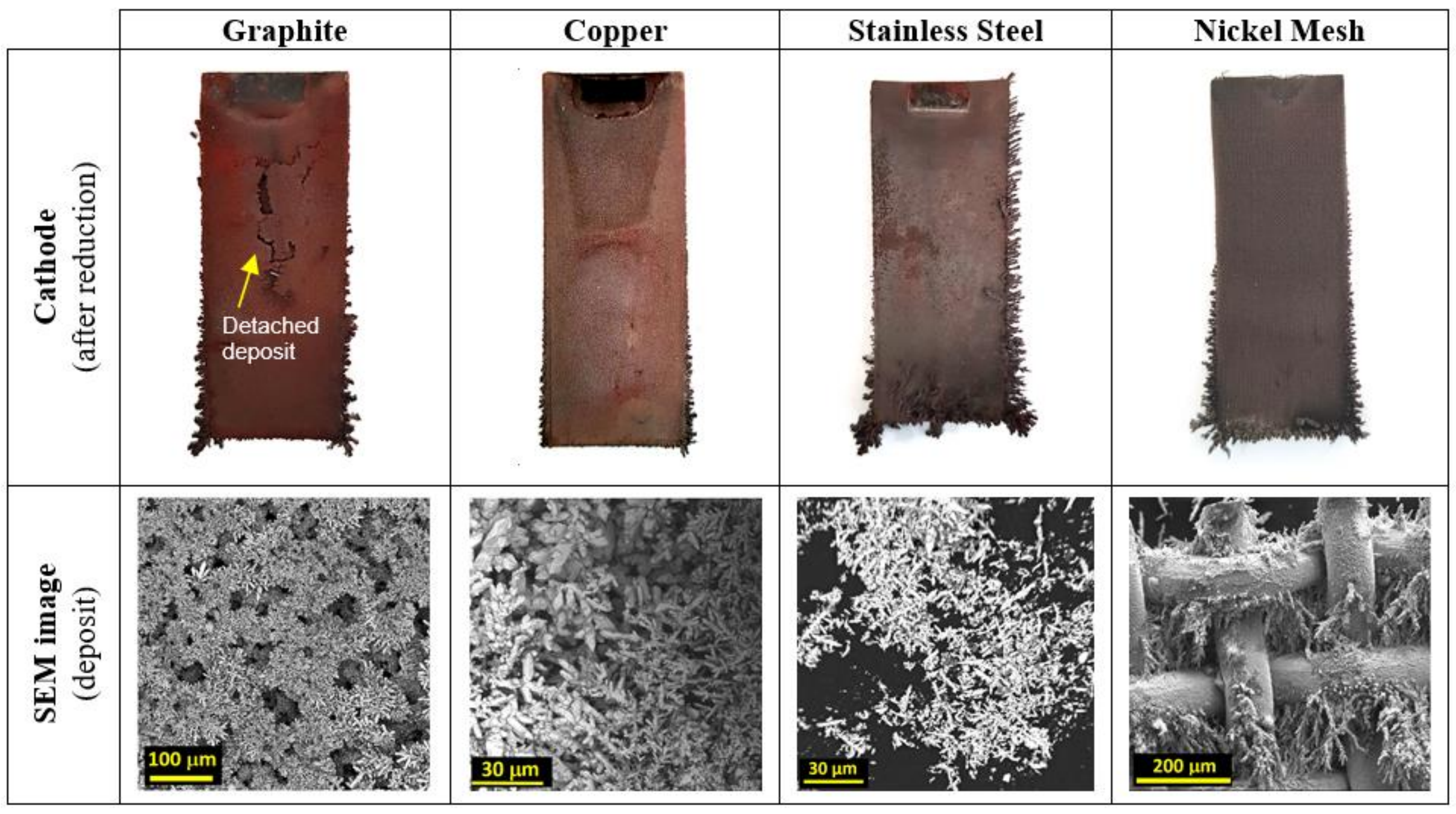

Fig 3. Various deposit types and microstructures in different cathode materials
(SEM Images were taken at: σ = 2000 A/m^2; ϕ = 20%)

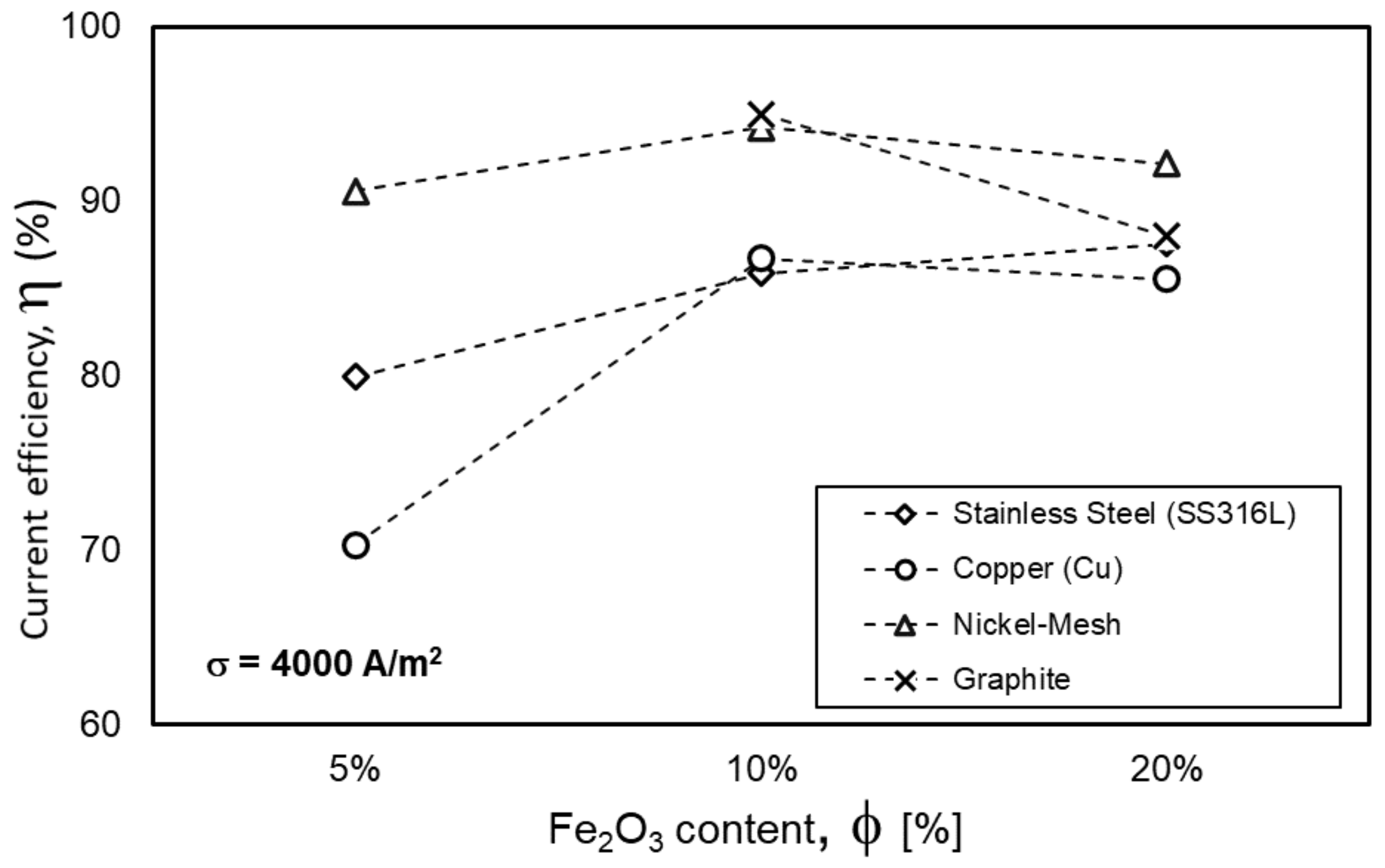

Fig 4. The current efficiency with different cathode material

Table 1. Practical justification among the cathode candidates

Criteria	Graphite	Copper	Stainless Steel	Nickel Mesh
Electrical conductivity	☹	☺	☺	☺
Mechanical strength	☹	☺	☺	☹
Electrode Porosity	☹	☺	☺	☹
Adherence/deposit strength	☹	☺	☺	☹
Oxidation in alkaline solution	☺	☹	☺	☺
Availability & price	☹	☹	☺	☹
Resulting dendritic iron	☺	☹	☺	☺

CONCLUSIONS

- Stainless steel is the preferred option.
- High current efficiency (>90%) is achieved for the electrochemical iron oxide reduction process.
- The cathode material influences the morphology of the iron deposit; However, it does not significantly influence the current efficiency.

FUTURE WORKS

- Systematic investigations of this iron regeneration process.
- Reactor design for iron oxide electroreduction to complete the iron fuel cycle.

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[1] Lavelaine et al. (2016), ULCOWIN Report: Iron production by electrochemical reduction of its oxide for high CO_2 mitigation, EU Project Report.
[2] Bergthorson (2018), Recyclable metal fuels for clean and compact zero-carbon power. Progress in Energy and Combustion Science 68, 169-196