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## Charge–Discharge Performance Evaluation of a Laboratory-Constructed Nickel–Iron Battery for Renewable Energy Storage Applications

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### Abstract

*The increasing deployment of renewable energy systems has created a growing demand for durable and environmentally friendly energy storage technologies. Nickel–Iron (Ni–Fe) batteries are promising candidates because of their long cycle life, tolerance to overcharging, and excellent durability. This study evaluates the charge–discharge characteristics of a laboratory-constructed Ni–Fe battery fabricated using nickel and iron electrodes with alkaline electrolyte. The battery was charged at a C/10 rate for 10 hours and discharged under different current rates to determine capacity retention, discharge behavior, energy efficiency, and operational stability. Experimental results showed a nominal cell voltage of approximately 1.2 V and discharge efficiencies ranging between 60% and 70%. The battery maintained stable voltage profiles throughout discharge and demonstrated minimal degradation after repeated cycling. Capacity remained between 80% and 90% under standard operating conditions, confirming the suitability of the battery for renewable energy storage. Although relatively high self-discharge was observed, the battery exhibited remarkable tolerance to overcharging and deep discharge. The findings demonstrate that the developed Ni–Fe battery possesses excellent durability and long-term reliability for stationary energy storage applications.*

### Keywords

Nickel–Iron battery, Charge-discharge, Renewable energy, Battery testing, Cycle life, Energy storage

## 1. Introduction

The rapid global transition toward renewable energy technologies has intensified the need for efficient, durable, and environmentally sustainable energy storage systems. Although renewable energy sources such as solar and wind are abundant and clean, their intermittent nature necessitates reliable storage technologies capable of ensuring continuous electricity supply (Bhattacharyya, 2022; IEA, 2024). Rechargeable batteries have therefore become indispensable components of modern energy systems, supporting grid stability, off-grid electrification, and distributed renewable energy applications (Hariprakash et al., 2005)

Among the available rechargeable battery technologies, lithium-ion batteries currently dominate the market because of their high energy density and excellent electrochemical performance. However, their widespread deployment is constrained by high production costs, dependence on critical raw materials, safety concerns associated with thermal runaway, and environmental challenges related to mining and recycling (Liu et al., 2023). Lead–acid batteries remain attractive because of their relatively low cost, but their short cycle life, limited depth of discharge, and environmental concerns associated with lead toxicity restrict their long-term sustainability (Posada et al., 2017). These limitations have renewed research interest in alternative battery chemistries based

on abundant, inexpensive, and environmentally benign materials.

Nickel–iron (Ni–Fe) batteries, originally developed by Thomas Edison in the early twentieth century, have re-emerged as promising candidates for stationary renewable energy storage due to their exceptional durability, long service life, resistance to overcharging and deep discharge, and the use of non-toxic, readily available electrode materials (Barton et al., 2020). Unlike many conventional battery systems, Ni–Fe batteries can remain operational for several decades with minimal performance degradation, making them particularly attractive for off-grid solar systems, microgrids, and remote energy installations where reliability is more important than high energy density (Abdallah et al., 2016)

Despite these advantages, several technical challenges continue to limit the widespread commercialization of Ni–Fe batteries. These include relatively low charge–discharge efficiency, high self-discharge rate, hydrogen evolution during charging, and comparatively low specific energy (Bhosale et al., 2023; Liu et al., 2023). Consequently, improvements in battery construction, electrolyte composition, electrode configuration, and operating conditions remain active areas of research aimed at enhancing electrochemical performance while preserving the inherent robustness of the technology (Wang et al., 2021).

This study evaluates the charge–discharge performance of a laboratory-constructed nickel–iron battery designed for renewable energy storage applications. The battery was fabricated using nickel and iron electrodes with alkaline electrolytes and subjected to controlled charging and discharging tests under different operating conditions. Performance indicators including discharge capacity, energy efficiency, voltage characteristics, cycle stability, and operational durability were investigated. Furthermore, the effects of potassium hydroxide (KOH) and sodium hydroxide (NaOH) electrolytes were compared to assess their suitability for Ni–Fe battery operation. The findings provide valuable insights into the feasibility of laboratory-fabricated Ni–Fe batteries as durable and environmentally sustainable energy storage devices for renewable energy systems (Zhang et al., 2021).

## 2. Materials and Methods

### 2.1 Materials

Nickel sheets and electrolytic iron sheets were used as the positive and negative electrode current collectors, respectively. Nickel hydroxide ( $\text{Ni}(\text{OH})_2$ ) served as the active cathode material, while iron acted as the anode material. Potassium hydroxide (KOH, >85%, ACS grade) and sodium hydroxide (NaOH, ACS grade) were employed as alkaline electrolytes. Distilled water was used for the preparation of all electrolyte solutions. The chemicals used in

this study were of analytical grade and were used without further purification.

### 2.2 Construction of the Nickel–Iron Battery

The laboratory-scale nickel–iron (Ni–Fe) battery was fabricated using nickel and iron electrodes housed in a non-reactive battery casing. The nickel and iron sheets were cut to dimensions of 160 mm × 158 mm × 340 mm and assembled into electrode plates to maximize the active surface area available for electrochemical reactions. A porous nylon separator was inserted between the electrodes to prevent electrical short-circuiting while allowing ionic transport through the electrolyte.

The assembled electrodes were positioned inside the battery casing and connected to external terminals. The electrolyte solution was then introduced into the cell before the battery was sealed to prevent leakage and minimize electrolyte evaporation during operation.

### 2.3 Electrolyte Preparation

Two alkaline electrolytes were investigated to evaluate their influence on battery performance. A 6 M potassium hydroxide (KOH) solution was prepared by dissolving 336 g of KOH pellets in distilled water and making the final volume up to 1 L. Similarly, a 6 M sodium hydroxide (NaOH) solution was prepared by dissolving 240 g of NaOH pellets in distilled water and diluting to 1 L. The solutions were

allowed to cool to room temperature before being transferred into the battery cells.

## 2.4 Charge/Discharge Testing

The electrochemical performance of the fabricated Ni-Fe battery was evaluated through controlled charge-discharge experiments conducted at ambient laboratory conditions ( $20 \pm 2^\circ\text{C}$ ). The battery was initially charged using a constant-current C/10 charging protocol for 10 h, corresponding to an average charging current of

approximately 0.21 A. After charging, the battery was discharged at different current rates until the terminal voltage reached the selected cut-off voltages (1.20, 1.10, 1.05, and 1.00 V per cell). Voltage, discharge time, and current were recorded throughout each experiment using a calibrated digital multimeter. Battery performance was evaluated based on discharge capacity, charge-discharge efficiency, voltage stability, cycle behaviour, and self-discharge characteristics.

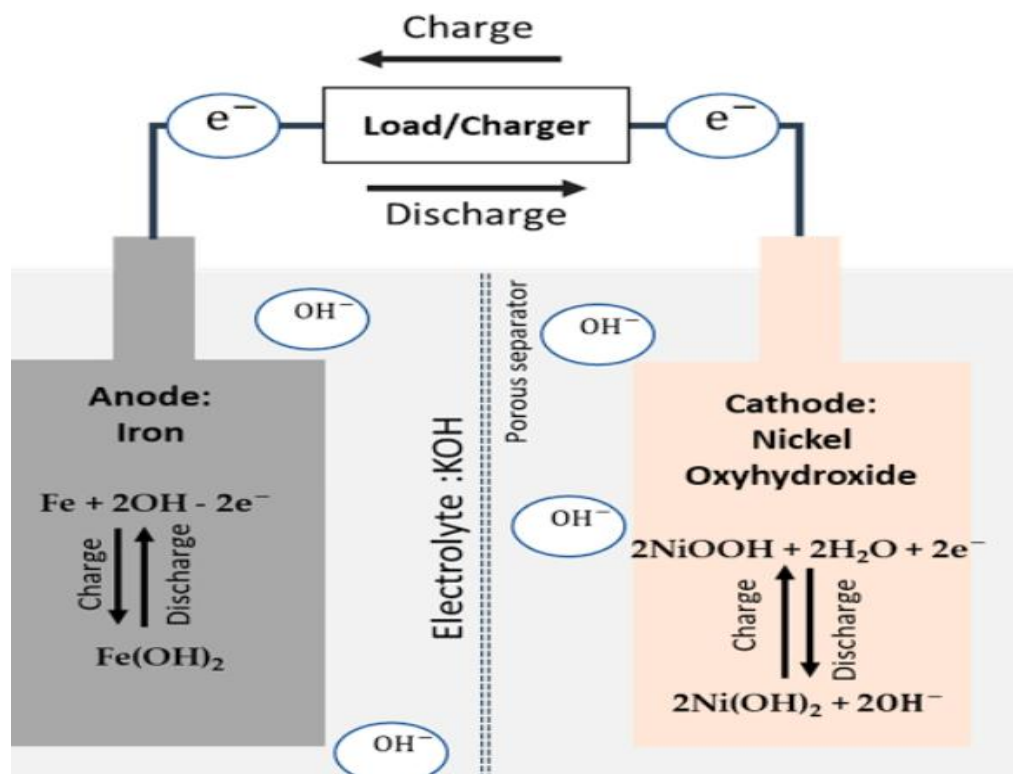


Figure: 2.1 Nickel iron battery cell charge and cell discharge (mason AF and Hart rb. 1975)

## 2.2.2 Testing and performance evaluation

The performance of Ni-Fe batteries is often evaluation through charge- discharge cycle

enabling assessment of efficient and capacity retention over time ongoing research by (longo A. and Doberiner G.E 1998) has established standardized testing protocols to ensure consistency in performance metric across different design.

### 2.3 The Concept of Nickel - Iron Battery

Nickel - Iron battery is a very robust battery, it has a very tolerance for overcharging, over discharging, short circuiting and also can perform equally well even when it is not charged for a long period of time (Smith *et al.*, 2022). The construction and development of nickel - iron batteries, also known as Edison batteries, have been a subject of interest and study for many years. These batteries were first patented by Thomas Edison in the late 19th century and were initially designed to be a rechargeable alternative to lead-acid batteries (Wang *et al.*, 2012).

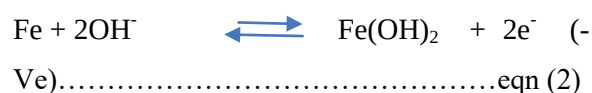
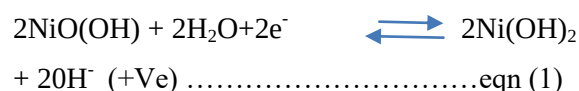
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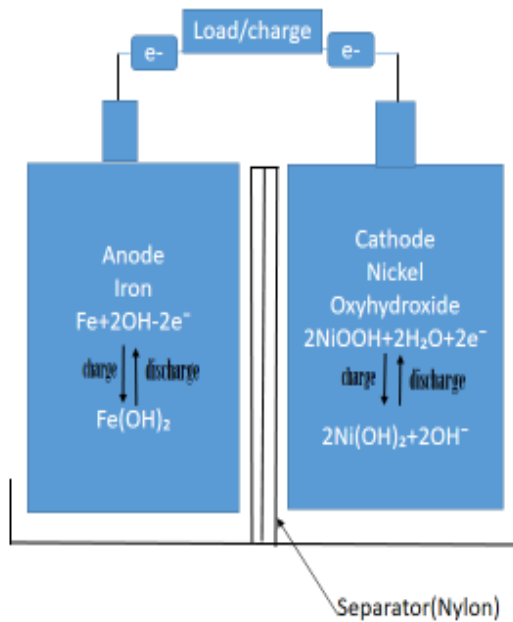
The battery is based on use of nickel oxyhydroxide (NiOOH) at the positive electrode and iron at the negative electrode. The charge–discharge reactions for the Ni–Fe battery are as follows:

The half-cell reaction at the positive plate from black nickel (III) oxide-hydroxide (NiOOH) to green nickel (II) hydroxide Ni(OH)<sub>2</sub>



(Discharging is read left to right, charging is from right to left (David Linden *et al* 2002).

The open-circuit voltage is 1.4 volts, dropping to 1.2 volts during discharge, The electrolyte solution of potassium hydroxide is not consumed in charging or discharging, so unlike a lead-acid battery the electrolyte specific gravity does not indicate state of charge, the voltage required to charge the Ni-Fe battery is equal to or greater than 1.6 volts per cell. The equalization charge voltage is 1.65 volts (David Linden *et al* 2002).



### 3. Results and Discussion

#### 3.1 Technical Characteristics of the Fabricated Nickel–Iron Battery

The results of the battery performance test (charge and discharge), durability, energy density and cycle life were presented in tables 3.1-3.3.

**Table 3.1 Technical Data**

|                                                                 |                                                             |            |                                                              |             |
|-----------------------------------------------------------------|-------------------------------------------------------------|------------|--------------------------------------------------------------|-------------|
| Voltage                                                         | 1.2V                                                        |            |                                                              |             |
| Capacity                                                        | 200AH                                                       |            |                                                              |             |
| Designed life                                                   | 30-50 years floating                                        |            |                                                              |             |
| Casing materials                                                | ABS                                                         |            |                                                              |             |
| Capacity (25°C)                                                 | 5HR (40A 1.0V)                                              |            | 200A                                                         |             |
| Dimensions                                                      | Length                                                      | Width      | Height                                                       |             |
|                                                                 | 160mm                                                       | 158mm      | 340mm                                                        |             |
| Approximate weight                                              | Dry                                                         | 10.0kg     |                                                              |             |
|                                                                 | Wet                                                         | 14.0kg     |                                                              |             |
| Electrolyte used                                                | KOH                                                         | NAOH       |                                                              |             |
| Volume of electrolyte                                           | 3.3L                                                        | 3.3L       |                                                              |             |
| Internal resistance                                             | Full charge at 25°C 1.0mΩ to 1.25 Mω                        |            |                                                              |             |
| Capacity affected by temp.                                      | 40°C                                                        | 20°C       | 0°C                                                          | 20°C        |
|                                                                 | 95%                                                         | 100%       | 85%                                                          | 50%         |
| Dual voltage, charging voltage and current voltage setting 25°C | Equalizing                                                  |            | Floating                                                     |             |
|                                                                 | 1.60V~1.7V/cell with initial charging current less than 40A |            | 1.48V~1.50V/cell with initial charging current less than 40A |             |
| Operating temperature                                           | Charging                                                    | 20 °C-60°C | Discharging                                                  | -40 °C-60°C |

The table presents the specifications and performance characteristics of a Nickel-Iron (Ni-Fe) battery, highlighting its durability, efficiency, and operating conditions.

The battery has a nominal voltage of 1.2 V per cell and a capacity of 200 Ah at a 5-hour discharge rate (40 A to 1.0 V). This indicates that the battery is capable of delivering a steady current over a defined period, making it suitable for applications that require long-duration energy supply, such as renewable energy storage systems.

In terms of durability, the battery has a designed life of 30–50 years under floating conditions, which is significantly longer than most conventional batteries. This extended lifespan makes it highly cost-effective over time, particularly in systems where frequent replacement is not desirable.

The construction of the battery includes a casing made from ABS (Acrylonitrile Butadiene Styrene), a material known for its strength and chemical resistance. This provides mechanical stability, resistance to corrosion, and protection against electrolyte leakage, thereby enhancing the overall reliability of the battery.

Physically, the battery has dimensions of 160 mm × 158 mm × 340 mm and weighs 10.0 kg when dry and 14.0 kg when wet. The difference in weight is due to the addition of electrolyte, which is essential for enabling the electrochemical reactions within the cell.

The electrolyte used in the battery consists of Potassium Hydroxide (KOH) and/or Sodium Hydroxide (NaOH), with a total volume of 3.3 L. These alkaline electrolytes provide high electrical conductivity, support long cycle life, and are less susceptible to degradation compared to acidic electrolytes, contributing to the battery's longevity.

The internal resistance of the battery ranges from 1.0 mΩ to 1.25 mΩ at full charge (25°C). This relatively low internal resistance minimizes energy loss, improves efficiency, and enhances the battery's ability to deliver high current when required.

Table 3.2 Performance after prolonged float charge of fully charged cells available Current  $20 \pm ^\circ\text{C}$

discharge time decreases as the discharge rate increases. For example, at 1.00 V/cell, the battery provides about 21.0 hours at the 10-hour

| END OFF<br>VOLTAGE<br>V/CELL | HOURS |      |      |      |      |     |     | MINUTES |     |     |     |     |     | SECONDS |     |     |
|------------------------------|-------|------|------|------|------|-----|-----|---------|-----|-----|-----|-----|-----|---------|-----|-----|
|                              | 10    | 8    | 5    | 3    | 2    | 1.5 | 1   | 30      | 20  | 15  | 10  | 5   | 1   | 30      | 5   | 1   |
| 1.00                         | 21.0  | 25.8 | 40.0 | 65.1 | 93.2 | 117 | 148 | 192     | 220 | 238 | 265 | 305 | 392 | 420     | 475 | 490 |
| 1.05                         | 20.6  | 25.0 | 39.6 | 63.0 | 89.0 | 110 | 133 | 172     | 190 | 212 | 230 | 266 | 342 | 368     | 412 | 430 |
| 1.10                         | 20.4  | 24.6 | 38   | 61.4 | 84.2 | 100 | 118 | 147     | 165 | 177 | 193 | 230 | 294 | 312     | 342 | 347 |
| 1.20                         | 20.2  | 24   | 37.6 | 59   | 75   | 87  | 100 | 125     | 138 | 147 | 165 | 191 | 250 | 270     | 291 | 300 |

The table presents the discharge performance of a fully charged battery maintained on float charge at approximately  $20^\circ\text{C}$  under different discharge rates and end-of-discharge voltages. The results show that lower cut-off voltages produce longer discharge times because they allow deeper utilization of the battery capacity. In contrast, higher cut-off voltages shorten the discharge duration. The data also indicate that

rate but only 490 seconds at the 1-minute rate. This reduction is mainly due to increased internal resistance, greater voltage drop, and lower effective capacity at higher discharge currents.

Table 3.3 Performance after charging the battery for 10hrs with 0.21A at  $20 \pm ^\circ\text{C}$

| END OFF<br>VOLTAGE<br>V/CELL | HOURS |      |      |      |      |       |      | MINUTES |      |      |     |     |     | SECONDS |     |     |
|------------------------------|-------|------|------|------|------|-------|------|---------|------|------|-----|-----|-----|---------|-----|-----|
|                              | 10    | 8    | 5    | 3    | 2    | 1.5   | 1    | 30      | 20   | 15   | 10  | 5   | 1   | 30      | 5   | 1   |
| 1.00                         | 21.0  | 25.8 | 40.0 | 65.1 | 88.5 | 105.0 | 129  | 159     | 180  | 193  | 212 | 242 | 310 | 332     | 375 | 387 |
| 1.05                         | 20.6  | 25.0 | 39.6 | 57.3 | 76.5 | 92.4  | 108  | 134     | 146  | 161  | 175 | 200 | 253 | 272     | 305 | 318 |
| 1.10                         | 19.8  | 23.4 | 34.2 | 51.0 | 67.4 | 78.0  | 89.7 | 107     | 120  | 127  | 137 | 161 | 206 | 218     | 239 | 243 |
| 1.20                         | 19.2  | 22.3 | 30.1 | 44.8 | 55.5 | 63.5  | 71.0 | 85.0    | 93.1 | 98.5 | 109 | 124 | 163 | 176     | 189 | 195 |

The table summarizes the battery discharge performance after a 10-hour charge at 0.21 A and  $20 \pm 2^\circ\text{C}$ . The results show that discharge time decreases as the end-of-discharge voltage increases. The battery achieved its longest

discharge time at 1.00 V/cell (21.0 h at the 10-hour rate), while the shortest time was recorded at 1.20 V/cell (19.2 h). Similarly, discharge time decreased with increasing discharge rate due to higher current demand, internal resistance, and

electrochemical losses. These findings indicate that lower cut-off voltages provide higher usable capacity, whereas higher cut-off voltages may enhance battery durability by reducing the depth of discharge.

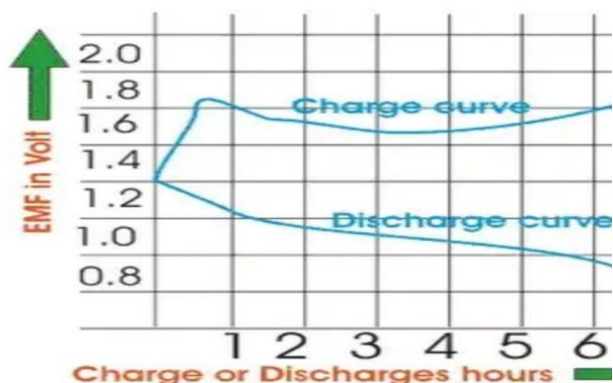


Figure: A Graph Shows Charge And Discharge Of Nickel Iron Battery

The graph illustrates the charge–discharge characteristics of a nickel–iron (Ni–Fe) battery by showing the variation of EMF with time. During charging, the voltage rises rapidly, experiences a slight dip due to polarization and internal resistance, and then gradually increases to a stable value as the battery approaches full charge. During discharge, the EMF decreases gradually, with a relatively stable voltage region before dropping sharply near the end of the cycle because of active material depletion and increased internal resistance. These results demonstrate the stable discharge behavior and good energy storage capability of the Ni–Fe battery.

#### 4. Conclusion

A laboratory-scale nickel–iron (Ni–Fe) battery was successfully fabricated and its charge–discharge performance was evaluated under different operating conditions. The battery exhibited a stable nominal voltage of approximately 1.2 V and demonstrated consistent discharge behavior across different discharge rates. Longer discharge times were obtained at lower end-of-discharge voltages, confirming improved utilization of the available battery capacity. Although higher discharge rates reduced the effective discharge time due to increased internal resistance and electrochemical polarization, the battery maintained satisfactory voltage stability throughout the discharge process. The results further demonstrate the excellent durability and suitability of Ni–Fe batteries for renewable energy storage applications where long service life and operational reliability are more important than high energy density. Future work should focus on improving charge efficiency, reducing self-discharge, and optimizing electrode materials and electrolyte composition to enhance overall battery performance.

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