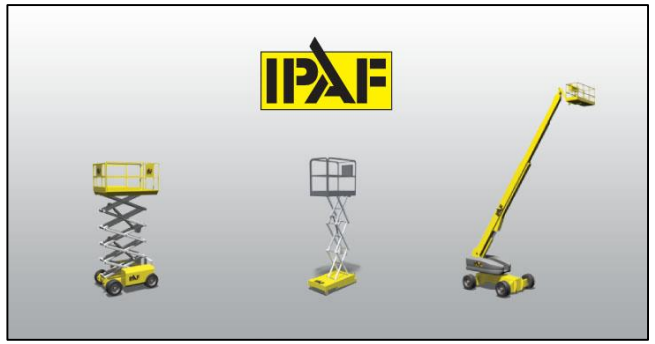

Battery Technologies for Mobile Elevating Work Platform (MEWP) Applications

July 17, 2019

TROJAN BATTERY COMPANY

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IPAF

IPAF ASIA CONFERENCE 2020
SEOUL, SOUTH KOREA
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MEWP – Deep Cycling Battery Requirements

- Selecting the correct battery technology is important to ensure complete customer satisfaction
- Managing customer expectations is key and this requires a complete understanding of their application and needs
  - Rented/leased equipment
  - Battery maintenance issues
  - Operating temperatures
  - Battery cost
- This presentation will describe various battery types and provide you with a full understanding of which one to select.

FLA

AGM

Li-Ion

MEWP – Deep Cycling Battery Requirements

- Factors to consider:
  - Daily usage (energy consumption)
  - Maintenance needs (watering/charging)
  - Cycle life
  - Charging time
  - Recyclability
  - Cost
  - Safety

- Depending on the above, there may be a good, better or best choice:
  - Flooded Lead Acid (FLA)
  - Absorbed Glass Mat (AGM)
  - Lithium-ion (Li-ion)

FLA

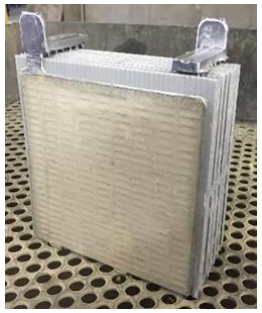
AGM

Li-Ion

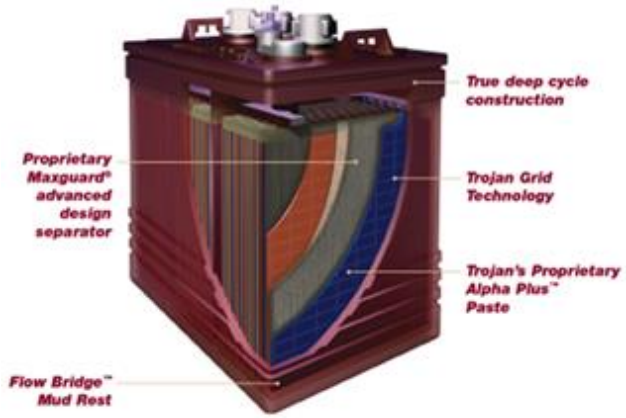
Flooded Lead Acid (FLA)

- Basic construction
  - Plate construction
    - Lead/antimony alloy grid
    - Active material: Lead (negative) or lead dioxide (positive)
  - Each 2V cell consists of
    - Set of negative plates connected together
    - Set of positive plates connected together
    - Separators between each plate
    - Electrolyte is dilute sulfuric acid
  - Package
    - Polypropylene/polyethylene co-polymer for recyclability, durability, and chemical resistance

- FLA batteries are identified by the vent caps allowing distilled water to be added when needed



Stack of plates and separators



Finished battery

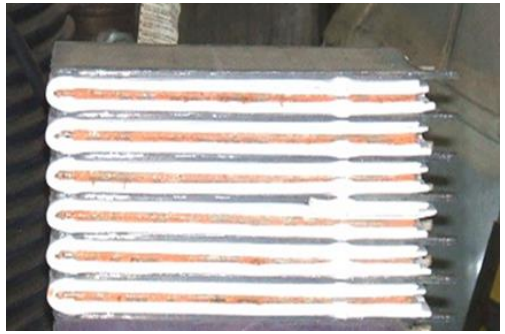
Characteristics of FLA Batteries

- Maintenance
  - Water must be added every 4 weeks or so, depending on usage to replace water lost during recharging (SPWS have helped but it is an additional cost)
  - Terminals must be periodically cleaned of corrosion
- Cycle life
  - ~1250 cycles at 50% DOD
- Charging time
  - 6 hours at 50% DOD
  - 8.5 hours at 100% DOD

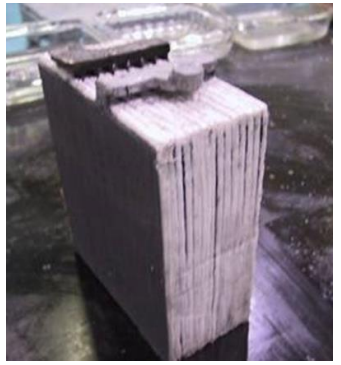
- Recyclability
  - Highly recyclable
  - Value in core
- Initial cost
  - Low
- Safety concerns
  - Hydrogen gas explosion hazard
  - Acid spills
- Initial Capacity
  - 70% increasing to 100%

Absorbed Glass Mat (AGM)

- Battery is sealed
  - No free electrolyte
  - Considered “sealed” and “non-spillable”
- Basic construction
  - Plate construction
    - Lead/calcium alloy grid
    - Active material: Lead (negative) or lead dioxide (positive)
  - Each 2V cell consists of
    - Set of negative plates connected together
    - Set of positive plates connected together
    - “Fiberglass” separators between each plate
      - Absorb and hold electrolyte
    - Entire stack is highly compressed before insertion into the case
  - Electrolyte is dilute sulfuric acid
  - Package
    - Polypropylene/polyethylene co-polymer
- AGM batteries are identified by the absence of fill ports



AGM plate/separator stack



AGM plate/separator stack after compression

Characteristics of AGM Batteries

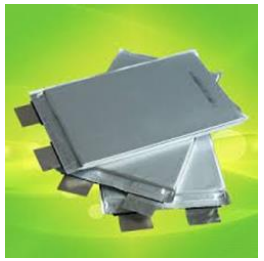
- Maintenance
  - No requirement for watering
  - Periodic cleaning of terminals recommended
- Cycle life
  - ~1200 cycles at 50% DOD
- Charging time
  - 4.6 hours @ 50% DOD
  - 9.2 hours @ 100% DOD

- Recyclability
  - Highly recyclable
  - Value in core
- Initial cost
  - Moderate - Higher than Flooded
- Safety concerns
  - Minimal
- Capacity
  - 100% within 10 cycles

Lithium Ion

- Basic construction
  - Positive electrode (cathode) – variety of chemistries
    - Lithium Cobalt Oxide (LCO)
    - Lithium Manganese Oxide (LMO)
    - Lithium Nickel Manganese Cobalt Oxide (NMC)
    - Lithium Iron Phosphate (LFP)
    - Lithium Nickel Cobalt Aluminum Oxide (NCA)
  - Negative electrode (anode)
    - Carbon
  - Separator
  - Electrolyte – lithium salt ($LiPF_6$) in an organic solvent
  - Package
    - Cylindrical
    - Prismatic
    - Pouch
- Safety concerns with lithium-ion batteries require the use of electronic Battery Management Systems (BMS) to monitor and protect the individual cells

18650 cylindrical cell



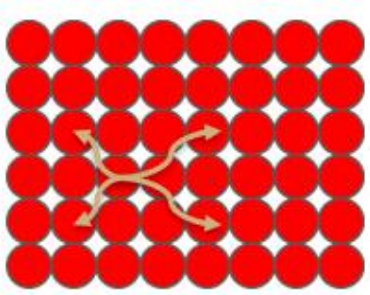
Pouch cells

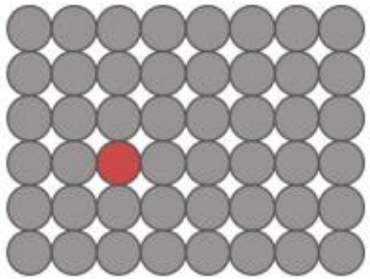
Prismatic

Li-Ion Chemistries

- Oxide based
  - NMC = Lithium Nickel Cobalt Manganese Oxide
  - NCA = Lithium Nickel Cobalt Aluminum Oxide
  - LCO = Lithium Cobalt Oxide
  - LMO – Lithium Manganese Oxide
    - Excess lithium can plate during overcharge
    - Significant oxygen evolution
    - Energetic thermal runaway above 150 °C
    - Rapid heat generation can lead to cell-to-cell propagation
    - Abuse tolerance important for large packs; one cell failure can cause its neighbors to fail
- Phosphate based
  - LFP = Lithium Iron Phosphate
  - LFMP = Lithium Iron Manganese Phosphate
    - No excess lithium in cathode
    - Little or no oxygen evolution
    - No energetic thermal runaway

Cell and pack design can help delay onset of event, but do not change fundamental chemistry of system.





Characteristics of Lithium-Ion Batteries

- Maintenance
  - None
- Cycle life
  - 6,000 at 70% DOD
- Charging time:
  - 2 hours @ C1 unless below 32°F
    - > 32°F (0°C) = 92A
    - 14° - 32°F (-10° to 0°C) = 12.5A
    - - 4° - 14°F (-20° to -10°C) = 5A
  - 3.3 hours at 50% DOD
  - 5.7 hours at 100% DOD
- Recyclability
  - Can be recycled
  - Cost of recycling exceeds value of materials recovered – fee involved
- Initial cost
  - High
- Safety concerns
  - Fire/explosion risk
  - Design and manufacturing quality extremely important
- Capacity
  - 100% at cycle 1

Performance Summary

	FLA	AGM	Li-Ion
Mounting & Environmental Restrictions	✓	✓ ✓ ✓	✓ ✓
Maintenance	✓	✓ ✓	✓ ✓ ✓
Power Capability	✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓
Cycle Life	✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓
Operating Temperature Range	✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓
Charging Time	✓ ✓	✓ ✓ ✓	✓ ✓ ✓
Recyclability	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓
Inherent Safety	✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓
Initial Cost	✓ ✓ ✓ ✓	✓ ✓ ✓	✓

✓ Depends on Chemistry/BMS

Technology Comparison Conclusion

- There is no one “Silver Bullet” for all MEWP applications.
  - Best choice will depend on customer requirements/expectations

- Some customers will want to have the “latest and greatest technology”, so having a variety of battery technology options will help satisfy all customers.

- With this information, hopefully you understand more about the various battery technologies and can provide the best battery choice to your customers.

Trojan Battery Company

would like to thank you for your time today. With over 90 years experience, Trojan Battery is the world's most trusted name in deep-cycle battery technology backed by our outstanding technical support team. Should you have any questions, please feel free to reach out to our Tech Support team.

technical@trojanbattery.com