Defence Science Journal, Vol. 73, No. 6, November 2023, pp. 757-764, DOI : 10.14429/dsj.73.6.19015

Feasibility Study of Lithium-Ion Batteries for Torpedo Applications

Sumeet Sunilrao Ragit[#], Karandeep Singh[#] and M. Srinivas[$,*]

[#]*Controllerate of Naval Armament Inspection (West), Naval Dockyard, Mumbai – 400 023, India*
[$]*DRDO-Naval Science & Technological Laboratory, Visakhapatnam - 530 027, India*
[*]*E-mail: srinivas.m.nstl@gov.in*

ABSTRACT

A comprehensive study on the feasibility of Lithium (Li)-ion battery technology for Light Weight Torpedoes (LWT) and Heavy Weight Torpedoes (HWT) applications are reported in this article. The global scenario of Li-ion battery technology for torpedo applications and current Indigenous Li-ion battery developments in India are studied. Configuration study of Li-ion battery for LWT and HWT with commercial cells was carried out and it is found feasible to partially meet the required power for LWT and HWT applications. A comparison of the cost per cycle of Li-ion battery versus AgO-Zn battery indicates that Li-ion batteries work out to be cheaper beyond 100 cycles of use and by an order of magnitude cheaper on average. The detailed survey on Indigenous developments reveals that cell-level development is predominant in public sector agencies, whereas the private sector is mostly focussed on the assembly of imported cells and BMS.

Keywords: Li-ion battery; AgO-Zn battery; Torpedo

1. INTRODUCTION

Batteries are essential for any underwater system due to the non-availability of AC power in isolated areas of operation. Submarines, AUVs and torpedoes are some of the major underwater systems which require batteries for propulsion. Among these, torpedoes require high-power batteries due to their higher speed of about 45-50 knots, though for a shorter duration of time (10-30 min.). Further restrictions in weight and volume are severe in torpedoes, unlike other underwater systems. Hence, AgO-Zn battery technology is being used for decades due to its capability of delivering high currents. The limitations in cycle life (10-15 cycles), limited wet life (less than 1 year), and requirement of maintenance cycle (even when not in use) force the designers to look for advanced Li-ion battery technology.

AgO-Zn battery chemistry is being used for many decades due to its high-power density compared to other existing battery systems. The theoretical specific energy density of AgO-Zn chemistry is 524 Wh/kg and the practical energy density is about 105 Wh/kg due to inactive components like battery hardware[1]. However, the degradation of AgO-Zn cells after each charging cycle, the limited cycle life of typically 10 cycles, higher maintenance, charge/discharge stand periods, etc., limit operational availability of AgO-Zn battery at full capacity and these disadvantages put a strict time frame on trials. So there is a need for an efficient battery technology. Li-ion battery technology offers many advantages viz., high energy density, higher per cell voltage (twice of the most commonly used secondary batteries), more charging cycles (a few hundred to thousand), requires negligible maintenance, freedom from charge/discharge stand period. The theoretical specific energy density of Li-ion battery chemistry is 410 Wh/kg and the practical energy density in battery form is about 150 Wh/kg[1]. Despite these advantages, the main limitation of Li-ion batteries is the availability of technology for the indigenous development of cells and battery management systems. The present-day Li-ion batteries use graphite or Lithium Titanate (LTO) as an anode and either $LiCoO_2$, $LiMn_2O_4$, or $LiFePO_4$ cathode. These batteries are available in various configurations i.e., cylindrical, prismatic, pouch, coin cell, etc., with capacities ranging from a few mAh to as high as 10,000 Ah. The cell voltage, specific energy, rate capability of discharge, and safety depends on the type of anode and cathode materials used.

Many countries have attempted the development of Li-ion batteries for practice version torpedoes. In 2004, M/s. Yardney has developed a Li-ion battery for torpedo application having 75 kW power using 25 Ah cells[2]. Later, it was upgraded to 90 kW power[2]. The modular construction of prismatic cells was adopted in this application with prismatic cell configuration. The batteries are reported to perform at a 10C rate of discharge[3-4].

SAFT has developed a Li-ion secondary battery for MU 90 LWT and HWT applications using cylindrical cells. Cells of 41 Ah capacity and 6-12 Ah capacity were reported to be used for HWT and LWT applications respectively[5]. The total battery power is 200 kW and 90 kW for HWT and LWT respectively. In the year 2013 first sea trials with Li-ion battery were reported[6]. Li-ion batteries based on Ni-based cathode require DC-DC convertors to compensate for dropping voltage characteristics and therefore $LiFePO_4$ chemistry was suggested for direct-driven motors due to its flat voltage profile[7]. It was reported that

Received : 31 March 2023, Revised : 09 June 2023
Accepted : 20 June 2023, Online published : 03 November 2023

the turnaround cost of Li-ion battery will be constant, unlike AgO-Zn which is escalating[7]. Hence, the choice of the cathode material was considered a trade-off between these parameters.

Advanced Lithium Systems Europe (ALSE), a joint venture company formed by Atlas Elektronik GmbH and Systems Sunlight S.A., has developed Li–ion cells, based on $LiFePO_4$ to be used in exercise batteries for heavyweight torpedoes[8]. The cells are compatible with AgO-Zn rechargeable cells for HWT that are still in use for these applications at present.

Kokam, one of the leading producers of Li-ion batteries in the world also claims the availability of customised solutions for torpedo batteries due to their experience in developing batteries for marine and defence applications[9]. The firm mostly manufactures pouch cells based on NMC ($LiNiMnO_2$) chemistry due to their high energy density with better heat dissipation, lower internal resistance (0.5 to 0.7 mΩ), and better efficiency compared to prismatic cells[9].

From the above survey, it is understood that different battery manufacturers adopt different configurations of cells, chemistry, and cell capacity to meet the required power for torpedo applications. However, only limited reports on the successful testing of torpedoes with Li-ion batteries are reported in the literature[6]. Further, details of the configuration of cells (series-parallel arrangement) and cost-benefit analysis are not available in the literature. This report, therefore, focuses on the configuration of batteries for LWT and HWT applications using Li-ion cells. Cost-benefit analysis and the present status of Li-ion battery technology in India are studied to understand the readiness of Indigenous development.

2. STATUS OF Li-ION BATTERY TECHNOLOGY IN INDIA

Vikram Sarabhai Space Centre (VSSC), Thiruvananthapuram initiated indigenous development of Li-ion battery technology for space applications. Li-ion cells of 1.5Ah, 50 Ah, and 100 Ah cells based on Lithium Nickel Cobalt Aluminium Oxide (NCA) chemistry suitable for Electric Vehicle transport and communication areas were developed by VSSC. Subsequently, the technology was transferred to BHEL in March 2019[10]. About 10 industries are reported to obtain technology licenses from VSSC. BHEL, Bangalore established a production facility primarily targeted to meet Li-ion cell requirements for ISRO and other strategic sectors based on the technology developed by VSSC[10].

International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) has set up a pilot plant facility for manufacturing Li-ion cells and battery packs for automotive applications in Chennai. Prismatic/cylindrical cells (up to 20 Ah) and LIB module up to 48V, 1 kWh was developed. On-road test trials have been conducted with e-cycle and e-scooter using Li-ion battery modules[11]. Several cathodes, anodes, and binder materials were developed along with the Flame Spray Process (FSP) for producing $LiFePO_4$.

Naval Science and Technological Laboratory (NSTL), Visakhapatnam, DRDO has developed High Power Li-ion Battery Technology and offers ToT to Indian industries[12]. ToT has been awarded to HBL Power Systems Pvt. Ltd., Hyderabad, and Bharat Electronics Ltd (BEL), Pune. The technology is based on $LiFePO_4$ chemistry and uses prismatic (Z-stacked) cell configuration unlike wound stacking used in many commercial applications. The development of an eco-friendly water-based binder instead of PVDF binders and in-house synthesis of $LiNiMnO_2$, $LiFePO_4$, $LiMn_2O_4$ cathode materials, and $Li_4Ti_5O_{12}$, SnCoC anodes is being carried out extensively.

Development of 28 V, 16 Ah Li-ion battery modules with BMS was carried out by IIT Kharagpur through the IMPRINT project funded by MHRD[13].

Central Electrochemical Research Institute (CECRI) has established a pilot-scale manufacturing plant under National Solar Mission Programme named Technology and Products with Sun Utilization Network (TAPSUN). Pouch type/18650 cells have been fabricated and initially demonstrated in various applications like Solar Lanterns, Power Bank, LED Flashlights, etc. Recently, CSIR-CECRI has also demonstrated an e-cycle powered by a Li-Ion battery pack of 18650 cells and an e-scooter by a Li-ion battery pack of prismatic cells (48 V/15 Ah). Presently, CECRI is involved in a CSIR-funded mission mode Project Innovation Centre for Next Generation Energy Storage Solutions (ICeNGESS) to set up a 100 MWh Li-ion Battery manufacturing plant[14].

Amara Raja Batteries, the country's second-largest automotive battery maker, has recently established a 10 MWh capacity Li-ion cells fabrication facility in Tirupati, Andhra Pradesh in Feb 2021 with the ToT from ISRO[15]. Exide Industries, the leading manufacturer of lead-acid storage batteries has also entered a joint venture with Leclanche, Switzerland, to build a Li-ion battery manufacturing facility of 1.5 GWh in Gujarat[16]. Tata Group has committed an investment of Rs 4,000 crore to set up a 10 GW Li-ion battery plant in the Dholera Special Investment Region (DSIR) of Gujarat.

IIT Hyderabad-incubated Start-up PURE EV has recently announced a collaboration with CSIR on indigenizing Li-Ion battery technology for electric vehicles. This collaboration was mainly on areas like Battery Thermal Management Systems (BTMS) and Safety which are critical for the mass-scale commercialization of this cells[17].

The Government of India approved a Production Linked Incentive (PLI) scheme with an outlay of ₹18,000 crores to promote the manufacturing and export of Advanced Chemistry Cell Batteries and their storage facilities[18]. This will promote the manufacturing, export, and storage of Li-ion cells, essential for developing electric vehicles. Through this scheme, the Union government aims to install a manufacturing capacity of 50 gigawatt-hour (GWh) of Advanced Chemistry Cells (ACC) and a 5 GWh capacity of Niche ACC. ACCs are essentially Li-ion cells. The government is eyeing direct investment of around ₹ 45,000 crore from leading battery manufacturers and hopes to save ₹ 2-2.5 trillion on account of a reduction in oil imports during the period of this program, due to increased adoption of electric vehicles. The scheme is expected to accelerate the adoption of zero-emission vehicles[18].

Many private industries work on Li-ion battery assembly along with BMS using imported cells in series/parallel combination to obtain the required power for 2-wheeler and 4-wheeler electric vehicles.

From the detailed survey, it is noted that most cell-level development activities are being carried out in the public sector and the private sector is mostly focused on the assembly of imported cells and BMS. With the increasing use of EVs, major battery manufacturing industries started venturing into the indigenous development of Li-ion cells. The high investment cost and lack of raw materials may be the reason for low investments in the private sector. However, with the new government policies, more industries are expected to emerge.

3. CONFIGURATION OF Li-ION BATTERY FOR LWT

In this section, the configuration of Li-ion batteries for LWT applications is carried out using commercially available cells. The details of the most common LWTs obtained from open literature are compared in Table 1. From this table, it is understood that the speed is 45 knots and the range is about 11 km for LWT.

To configure a battery for any given application, it is required to know battery parameters viz., voltage, current, endurance (time of operation), space, and weight available. The parameters are calculated/listed in Table 2 for LWT.

Table 1. Parameters of LWT from open literature

Parameter	A244S	MU90	Stingray
Country	Italy	French/Italy	British
Length (m)	2.75	2.85	2.6
Weight (kg)	254	304	267
Max. speed (knot)	36	50	45
Battery	Mg-AgCl	Al-AgO	Mg-AgCl
Range (km)	13	10	8-11

Table 2. Battery parameters for typical LWT applications

Parameters	Value
Battery diameter	300 mm[19]
Length	1000 mm[20]
Power required	75 kW[21]
Voltage required	400 V[21]
Current =Power /Voltage	187 A
Endurance= Speed/range	~ 10 min
Capacity required in Ah=current*endurance in min/60	31 Ah

To meet the above parameters, the cells available in the market and those surveyed in the literature are considered and configuration is calculated in Table 3.

The configuration calculated in Table 3 with 40 Ah prismatic cells of ALSE, Greece make requires 125 cells to meet the voltage. Configuration of the cells that can be accommodated was prepared using 2D AUTOCAD drawings, considering the dimensions of cells and battery compartment. Front and side views of the battery compartment with cells are shown in Fig. 1. The total number of cells that can be accommodated is the product of cells in front and side views. The number of cells required to meet voltage is 125 whereas that can be accommodated is only 60. Therefore, it is not feasible to configure the battery within the available space with these cells.

The configuration with 30 Ah pouch cells of Kokam requires about 111 cells primarily to meet the voltage. The required number of cells, in this case, is lower than that of ALSE make due to the use of $LiNiMnO_2$ chemistry (NMC) which has a higher nominal voltage of 3.6 V. The arrangement of cells within available space in Fig. 1(b) indicates that only 100 cells

Table 3. Battery configuration with commercial cells for LWT application

Parameter	ALSE	KOKAM	Commercial 32650
Cell type and capacity	Prismatic cell-40 Ah	Pouch cell-30 Ah	Cylindrical cell-6 Ah
Chemistry	LFP	NMC	LFP
Single-cell dimensions	80mm L x 50mm W x 176mm H	126 mm L x 10 mm W x 127 mm H	32 mm ø, 65 mm H
Single-cell weight	1.43 kg	0.99 kg	0.147 kg
Single-cell Voltage	3.2 V	3.6 V	3.2 V
Single-cell current	160 A (4C)	320 A (8C)	18 A (3C)
No. of cells required for voltage	125	111	125
No. of parallel strings required for current	01	01	10
No. of parallel strings required for endurance	01	01	05
Required configuration (considering highest of above)	125S1P	111S1P	125S10P
Total number of cells required	125 cells	111 cells	1250 cells
Number of cells that can be accommodated	60 cells (Fig. 1(a)	100 (Fig. 1(b)	875 (Fig. 2)
Feasibility	No	No	Partially
Feasible battery details	NA	NA	400 V, 126 A125S7P 50.4 kW, 10 min endurance, 8.4 kWh

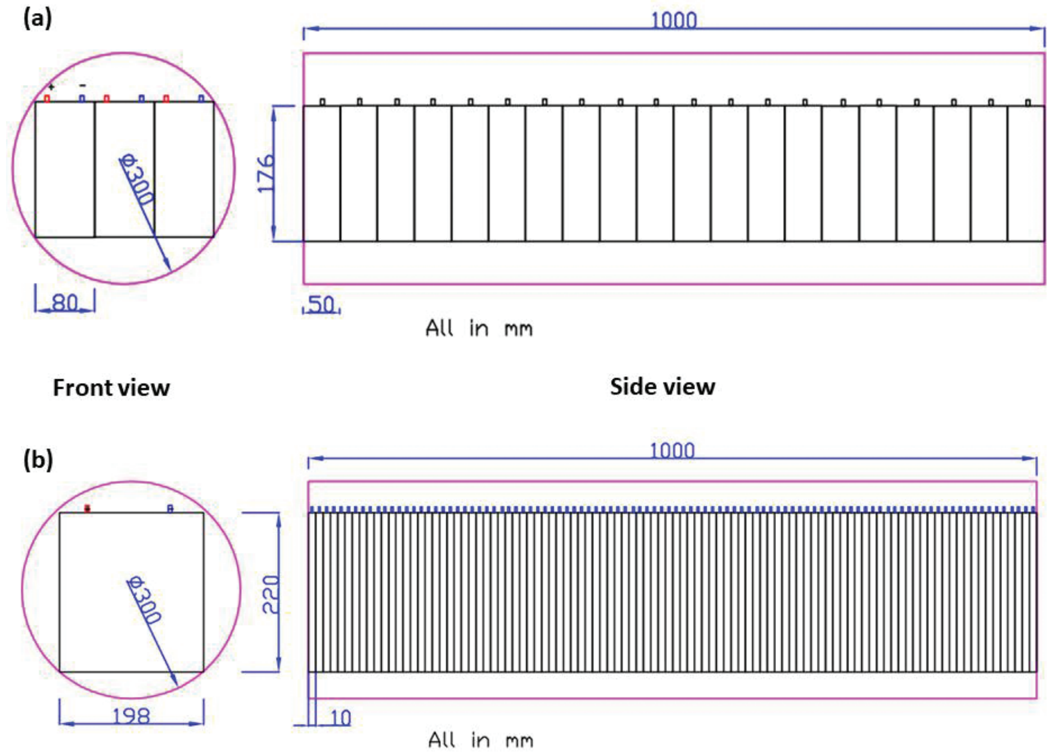

Figure 1. LWT Li-ion battery configuration with a) ALSE 40 Ah prismatic cells b) Kokam 30 Ah pouch cells.

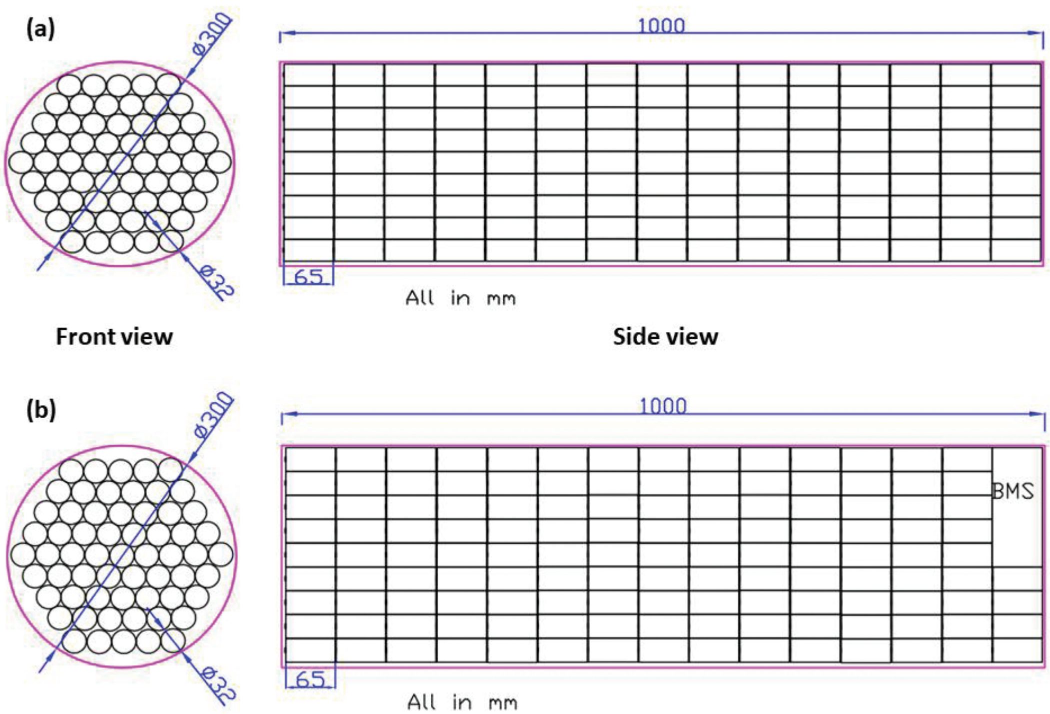

Figure 2. LWT Li-ion battery configuration with commercial 32650 cells: (a) 915 cells and (b) 125S7P.

can only be accommodated. BMS can be accommodated in the leftover space on top.

The configuration with 32650 type cylindrical cells of any commercial make with 6 Ah capacity requires 1250 cells (125S10P) to meet power. The cells required for meeting endurance is 625 cells (125S5P). The maximum number of cells among that calculated value for voltage, and endurance is to be considered to meet both power and endurance i.e., 1250 cells. However, from the configuration with these cells in Fig. 2(a), it is realized that only 915 cells can be accommodated (61 in front view x 15 in side view). Therefore, the required power cannot be met, though endurance can be met. Considering accommodating 875 cells to achieve 125S7P configuration, a power of 50.4 kW and 10 min endurance is feasible. The excess

Table 4. Parameters of HWT from open literature

Parameters	Black shark	F-21	DM24A
Country	Italy	French/Italy	Germany
Length (m)	6.3	6.0	6.6
Weight (kg)	--	1550	--
Max. speed (knot)	50	50	50
Battery type	Al-AgO	Al-AgO	AgO-Zn
Range (km)	50	50	50

Table 5. Typical battery parameters for HWT applications

Parameters	Value
Battery diameter	500 mm[19]
Length	2500 mm[20]
Power required	250 kW[21]
Voltage required	400 V[21]
Current =Power /Voltage	625 A
Endurance = speed/range	32 min
Capacity required in Ah =current*endurance/60	330 Ah

Table 6. Calculation of battery configuration with commercial cells for HWT application

Parameter	ALSE	KOKAM
Capacity	120 Ah	40 Ah
Chemistry	LFP	NMC
Single-cell dimensions	137mm L x 81mm W x 178mm H	226 mm L x 10 mm W x 227 mm H
Single-cell weight	4.03 kg	1.27 kg
Single-cell voltage	3.2 V	3.6 V
Single-cell continuous current	480 A (4C)	320 A (8C)
No. of cells required for voltage	125	111
No. of parallel strings required for current	02	02
No. of parallel strings required for capacity	03	08
Required configuration (considering highest of above)	125S3P	111S8P
Total number of cells required	375 cells	888 cells
Number of cells that can be accommodated	156 cells (4 x 30 + 3 x13)	676 (64 x 10 + 18)
Feasible power, endurance	125S1P 192 kW, 12 min	111S6P 250 kW, 23 min

space can be utilised for BMS. The revised configuration with 875 cells and BMS is shown in Fig. 2(b).

The configuration calculation of a Li-ion battery for LWT application indicates that with 32650 cells it is feasible to configure a battery with limited power (50.4 kW instead of 75 kW). Due to space constraints, configuration with other cells is not feasible as the voltage is not met. However, with relaxations in the voltage power and endurance, configuration with other cells may be possible.

4. CONFIGURATION OF Li-ION BATTERY FOR HWT

The details of the most common HWTs obtained from open literature are compared in Table 4. The range and speed are 50 km and 50 knots respectively. Details of battery parameters obtained from the literature are given in Table 5.

To meet the above parameters, the cells available in open market and those surveyed in the literature are considered and the configuration is given in Table 6.

The configuration with 120 Ah prismatic cells of ALSE, Greece requires 250 cells to meet voltage and current. The arrangement of the cells within the available space indicates that only 156 cells can only be accommodated (Fig. 3(a)). However, 125 cells can be configured, and the remaining space can be utilised for BMS. Thus, a battery with limited power and range (192 kW, 12 min, 18 km) can be realised which is slightly lower than the required power (250 kW) and endurance (32 min).

Configuration with 40 Ah pouch cells of Kokam requires about 888 cells to meet voltage and endurance. The arrangement of the cells in Fig. 3(b) indicates that 676 cells can be accommodated within the available space, leaving space for BMS. With these cells, a battery with about 250 kW power and 23 min endurance, a 36 km range is feasible. This is higher than the power and range possible with prismatic cells due to pouch configuration.

The configuration calculation of Li-ion battery for HWT applications indicates that with limited power and endurance/range is feasible to realize a battery with either pouch or prismatic cells.

5. COST BENEFIT ANALYSIS

In this section, the cost of a Li-ion battery is compared with that of AgO-Zn. The calculation is based on the following assumptions:

- The cost of an AgO-Zn LWT battery is approx. 50 lakhs
- The cost of an AgO-Zn HWT battery is approx. four times that of a LWT battery as the power and range are approximately four times higher
- The cost of a Li-ion battery is approximately four times that of an AgO-Zn battery
- Return of cost from extracted silver from an AgO-Zn battery would be about 50 % and nil in the case of a Li-ion battery
- The recurring and disposal cost of both batteries is assumed to be similar for both batteries
- The life of an AgO-Zn is 10 cycles and that of a Li-ion battery is 500 cycles

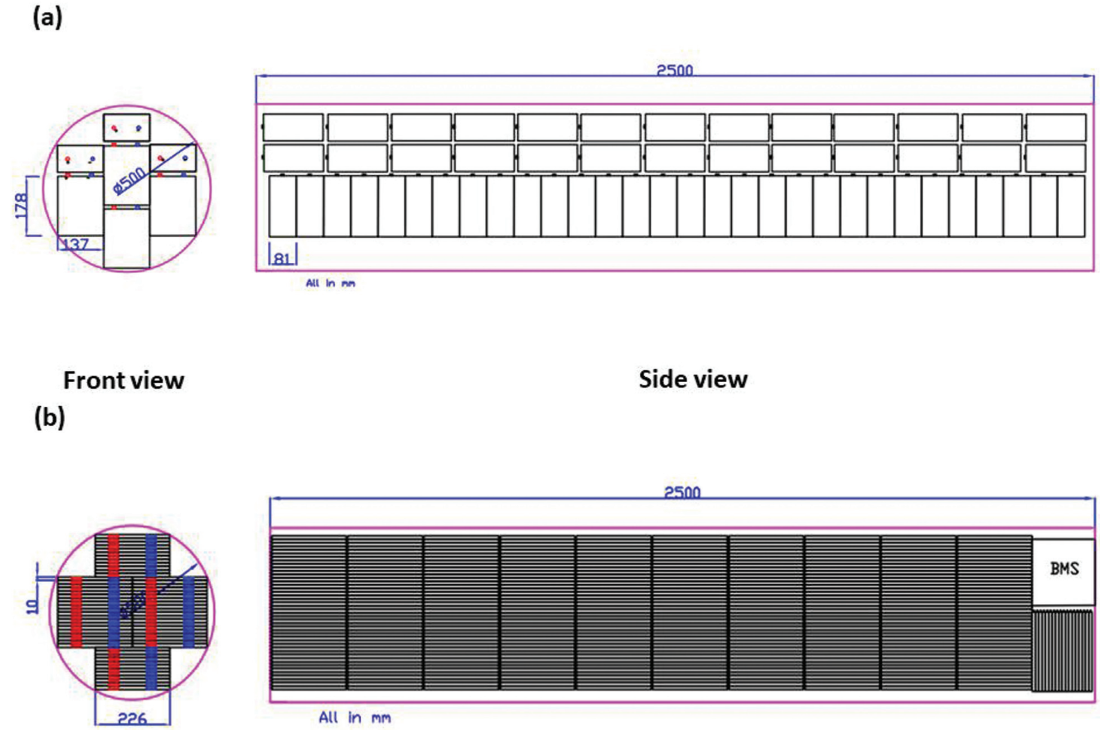

Figure 3. HWT Li-ion battery configuration with a) ALSE 120 Ah prismatic cells b) Kokam 40 Ah pouch cells.

Table 7. Average cost per cycle using AgO-Zn and Li-ion battery for LWT and HWT

	LWT		HWT	
Parameters	AgO-Zn	Li-ion	AgO-Zn	Li-ion
Cost (in lakhs)	50	200 (4x of AgO-Zn)	200 (4x of LWT)	800 (4x of AgO-Zn)
Return of silver (50 % of original cost)	25	0	100	0
Cycle life	10	500	10	500
Average cost per cycle (in lakhs) for full battery life	2.5	0.4	10	1.6

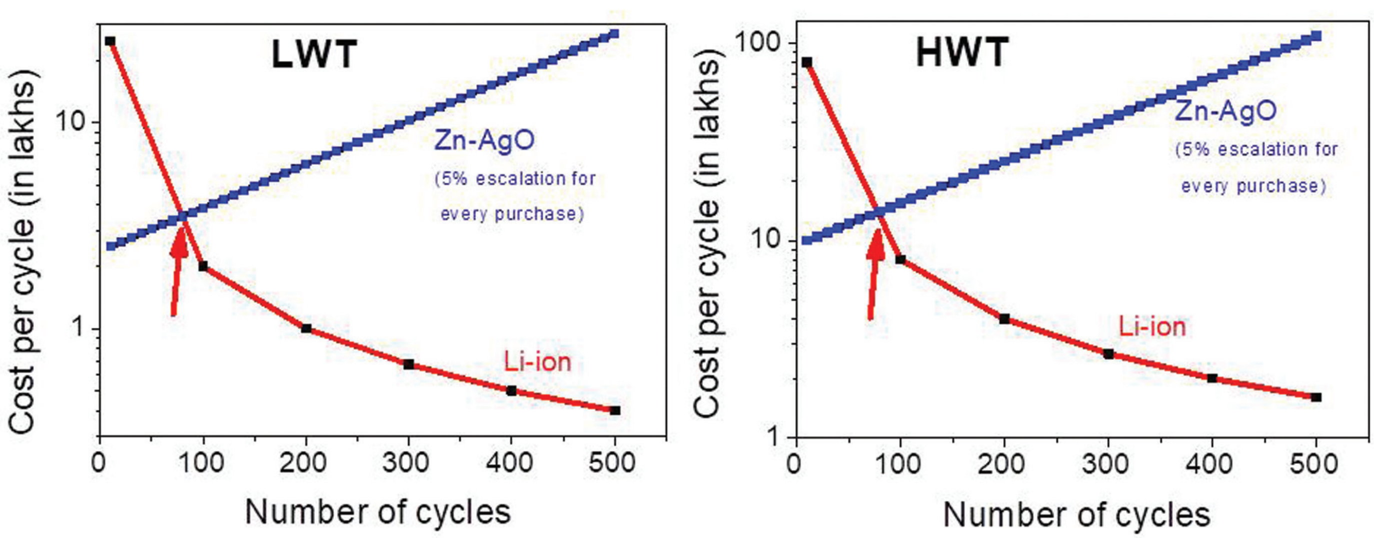

Figure 4. Estimated cost per cycle for using AgO-Zn and Li-ion battery for LWT and HWT.

- The escalation price of an AgO-Zn battery when purchased after 10 cycles would be 5 per cent.

With the above assumptions, the average cost per cycle of AgO-Zn battery for LWT and HWT batteries is calculated and shown in Table 7.

From the table, it is observed that the cost per cycle using a Li-ion battery is an order of magnitude cheaper than an AgO-Zn battery, which is apparently due to the order of magnitude higher life of a Li-ion battery. To resolve this, the cost per cycle with the number of cycles of usage is plotted for LWT and HWT applications in Fig. 4. From the cost per cycle versus the number of cycles graph, it is interesting to note that Li-ion is cost-effective beyond 100 cycles of usage and would be cheaper by an order of magnitude subsequently. Thus, a break-even point in cost-effectiveness is determined in this study.

5.1 Carbon Foot-Print of Li-ion Batteries

Li-ion batteries are reported to have greenhouse gas emissions of up to 41-89 kg/kWh for production[22]. It is expected that the value may reduce to 10-45 kg/kWh by 2050 due to the low-carbon electricity transition[22] After use in electric vehicles, Li-ion batteries can have after-life uses in stationary applications such as UPS and energy storage and are known as second-life applications[23]. After full utilization, recovery of Lithium mostly in the form of Li_2CO_3 from the cathode materials is being carried out to synthesize fresh cathode materials[24]. These steps ensure complete recycling of the Li-ion batteries similar to other batteries and reduce carbon footprint.

6. CONCLUSIONS

In this study, the feasibility of using Li-ion batteries for torpedo applications is studied and the following conclusions are drawn:

- Configuration study of Li-ion battery for light weight and heavy weight torpedoes with commercial cells indicates feasibility in meeting the required power partially. Meeting the full power is not feasible as AgO-Zn can withstand high rates of discharge/current density compared to Li-ion. However, Li-ion offers operational advantages viz., higher cycle life and lower maintenance compared to AgO-Zn
- A comparison of the cost per cycle of the Li-ion battery vs. AgO-Zn battery indicates a break-even point in cost-effectiveness exists beyond 100 cycles for Li-ion batteries
- Indigenous development of Li-ion batteries was mostly in the public sector, whereas the private sector is focused on the assembly of imported cells and BMS. However, major battery manufacturing industries have initiated indigenous production of Li-ion cells
- Being a relatively newer technology, maintenance requirements viz., replacement of faulty cells or faults in the BMS hardware will require support from the original equipment manufacturer
- Li-ion batteries for torpedoes require custom design and this involves rigorous R&D and testing which needs to be initiated for realizing batteries for future applications.

REFERENCES

1. Linden, D. & Reddy, T.B. Handbook of batteries, Ed.3, McGraw-Hill, 2002.
2. Gitzendanner, R.; Puglia, F. & Santee, S. Advances in the energy and power density of lithium-ion batteries for undersea applications. Yardney Technical Products Inc., USA UDT 2009.
3. Yalen, W.J. Advanced lithium-ion batteries applications and material considerations. Yardney Technical Products Inc., USA, 2009.
4. Cohen, S. & Puglia, F. Design and performance of Li-ion cells for underwater energy storage and power delivery. Yardney Technical Products Inc.
5. Gitzendanmer, R.; Puglia, F.; Martin, C.; Carmen, D.; Jones, E. & Eaves, S. High power and high energy lithium-ion batteries for under-water applications. *J. Power Sources*, 2004, 136, 416-418. doi: 10.1016/j.jpowsour.2004.03.032
6. A torpedo powered by a lithium-ion battery breaks speed records in complete safety. *Naval Technology.* www.navyrecognition.com (Accessed on 17 April 2023).
7. Poirier, F. & D'Ussel, L. Lithium-ion battery technology – A saft white paper. https://www.saft.com/media-resources/knowledge-hub/white-papers/li-ion-technology-exercise-torpedoes. (Accessed on 17 April 2023).
8. Li-ion cell datasheets ALF 40H, 120H www.lithium-systems.com. (Accessed on 15 May 2021)
9. Military battery, Kokam. https://kokam.com/en/businessmilitary-battery. (Accessed on 17 April 2023).
10. Transfer of VSSC developed lithium ion cell technology to industries, ISRO. www.isro.gov.in. (Accessed on 17 April 2023).
11. Development of lithium-Ion batteries for electric vehicles, ARCI. https://arci.res.in/programmes-caem#5. (Accessed on 17 April 2023).
12. Development of high power Li-ion battery technology, DRDO. https://www.drdo.gov.in/transfer-technologies. (Accessed 17 April 2023).
13. Development of high energy and high power density lithium ion battery for underwater application, IMPRINT India. www.imprint-india.org. (Accessed 17 April 2023).
14. Li-ion battery, CECRI. www.cecri.res.in. (Accessed 17 April 2023).
15. Raja, A. Begins work on lithium-ion cells, sets up research hub at Tirupati, Economic Times. www.auto.economictimes.indiatimes.com (Accessed on 21 February 2021).
16. Exide Industries, India's largest manufacturer of batteries, and Leclanché announce the launch of a new joint venture to build lithium-ion batteries and energy storage solutions to power the growth of India's electric vehicle market, www.leclanche.com (Accessed on 27 June 2018)
17. IIT Hyderabad incubated startup to collaborate with CSIR-CECRI to support 'Atmanirbhar Bharat' Mission, *India Today.* (Accessed on 16 Dec 2020).
18. PLI scheme to help India develop as manufacturing hub for EV cells. *Livemint*www.livemint.com (Accessed on 13 May 2021).
19. Rear Adm. (Retd) Ramanarsaiah, VSM. Introduction to torpedo technology, *DRDO Monograph Series,* 1993, **1**.

20. Battery for torpedo, Korea Special battery Co. Ltd. www.ksbatteries.com
(Accessed on 17 April 2023).
21. Underwater system technologies. *Technology Focus*, 2013, **21.**
22. Xu, C.; Steubing, B.; Hu, M.; Harpprecht, C.; Meide, Marc van der & Tukker, A. Future greenhouse gas emissions of automotive lithium-ion battery cell production. *Resour., Conserv. Recycl.,* 2022, **187**, 106606.
doi: 10.1016/j.resconrec.2022.106606
23. Meegoda, J.N.; Malladi, S. & Zayas, I.C. End-of-Life management of electric vehicle lithium-ion batteries in the United States. *Clean Technol.*, 2022, **4**, 1162–1174.
doi: 10.3390/cleantechnol4040071
24. Rao, A.N.; Jagadish, K. & Rajasekhar, A. Recovery of lithium precursors from spent $LiFePO_4$ electrodes, National Seminar on Electrochemical Energy Conversion & Storage, Sep. 2023

CONTRIBUTORS

Lt Sumeet Sunilrao Ragit was commissioned in Indian Navy in Dec 2018. He obtained MSc (Naval Military Technology) from SPPU, Pune. His areas of interest include: Inspecting guns, torpedo tubes and rocket launchers onboard ship/submarine/Naval establishments.
His contributions in this research work are: Carrying out literature survey and preparation of Li-ion battery configuration for light and heavy torpedo.

Mr Karandeep Singh is a Lieutenant serving in the Indian Navy's Naval Armament Inspection cadre and hails from Mohali, Punjab. He obtained his MSc (Naval Armament Technologies) from Military Institute of Technology, Pune. His areas of interest include: Static firing the rocket motors of various naval missiles as well as functional trials of numerous Naval Armament Stores (NAS).
His contributions in this research work are: Carrying out literature survey and preparation of Li-ion battery configuration for light and heavy torpedo.

Dr M. Srinivas is a Scientist in DRDO-NSTL, Visakhapatnam. He obtained Doctorate in Metallurgical & Materials Engineering. His areas of research include: Batteries, magnetic materials, rapid solidification and metallic glasses.
His contributions in this research work are: Carrying out cost-benefit analysis and preparation of manuscript.