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ON THE ELECTRIC PROPULSION OF RIVER SHIPS

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ABSTRACT

Electric propulsion for river ships is an exciting and promising development in the maritime industry. This technology involves using electric motors powered by batteries instead of traditional internal combustion engines. Advances in battery technology, such as lithium-ion batteries, have made electric propulsion more viable and cost-effective. It is generally more efficient than internal combustion engines, leading to a better fuel economy and lower operational costs and it produces significantly less pollution compared to traditional engines, which burn heavy oil. This helps reduce greenhouse gas emissions and other pollutants like NOx and particulate matter. Plus, electric motors are quieter than traditional engines, making electric ships more suitable for operations in urban areas and sensitive environments. There are also some ships using hybrid systems that combine electric propulsion with traditional engines, allowing them to switch between power sources depending on the situation.

Keywords: electric propulsion, batteries, all-electric tugboat, emissions

1. INTRODUCTION

The river fleet must face major challenges:

Improve environmental performance

• Reduce fuel consumption;
• Reduce emissions and pollutant discharges;
• Encourage the use of renewable energies;
• Optimize energy management on board.

Better integrate the river link into logistics chains

• Capture new traffic;
• Consolidate river service to seaports;
• Improve the logistics performance of the river fleet.

Complying with the regulation on emissions from Non-Road Mobile Machinery (NRMM)

The European Commission has adopted this regulation, which applies in particular to inland waterway vessels, the aim of which is to progressively reduce pollutant emissions and phase out the most polluting engines. The regulation of emission control is a succession of many stages: stage V will replace stages I to IV.

New limits are imposed on ship owners regarding engine performance, when the engine is installed after the date of entry into force of the regulation (2019-2020). Thus, under the stage V regulation, engine emissions must be significantly restricted. The stage V limits, in accordance with the table below, apply to propulsion (IWP) and auxiliary (IWA) engines of more than 19 kW, regardless of the engine ignition type.

Table 1 - Stage V emission standards for inland waterway vessel engines (IWP and IWA)

Category	Net Power [kW]	Date	CO [g/kWh]	HC [g/kWh]	NOx [g/kWh]	PM [g/kWh]	PN 1/kWh
IWP/IWA-v/c-1	19 ≤ P > 75	2019	5.00	4.70		0.30	
IWP/IWA-v/c-2	75 ≤ P > 130	2019	5.00	5.40		0.14	
IWP/IWA-v/c-3	130 ≤ P > 300	2019	3.50	1.00	2.10	0.10	
IWP/IWA-v/c-4	P ≥ 300	2019	3.50	0.19	1.80	0.015	$1x10^{12}$
CO: carbon monoxide; HC: hydrocarbons; NOx: nitrogen oxides; PM: average particle mass; PN: number of particles							

2. ELECTRICAL ARCHITECTURES

The electrical concepts are numerous and must always be evaluated according to the operational profile of the boat, which defines the needs and the most suitable technical solution.

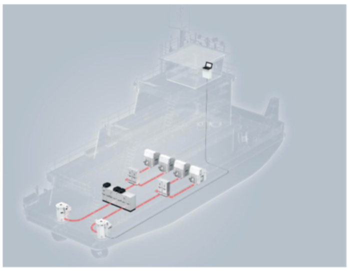

Fig.1. Skematic electric architecture

When moving towards an electric design, the number and size of cylinders on the thermal engines of the energy plant are reduced to the bare minimum. This allows the highest possible engine efficiency to be obtained.

There are three types of electric or hybrid solutions.

The parallel hybrid concept

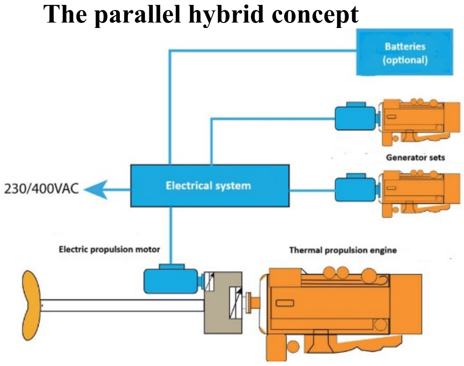

Fig.2. The parallel hybrid concept skematic

The electric motor is mounted in parallel with the drive shaft line. Depending on the need (urban environment, maneuver, etc.), the thermal or/and electric motor can be used alternately.

ADVANTAGE: the electric motor, thus mounted on the reducer, will be small.

The series hybrid concept

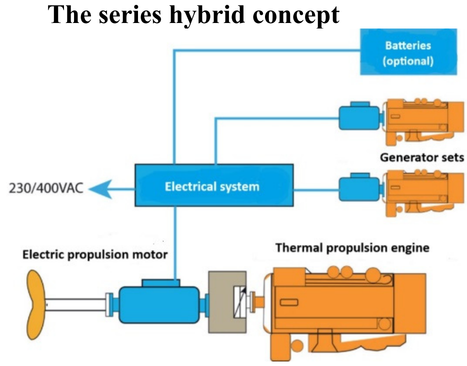

Fig.3. The series hybrid concept skematic

The electric motor is mounted in series on the propulsion shaft line.

ADVANTAGE: no mechanical loss linked to the absence of a reducer.

The electric concept

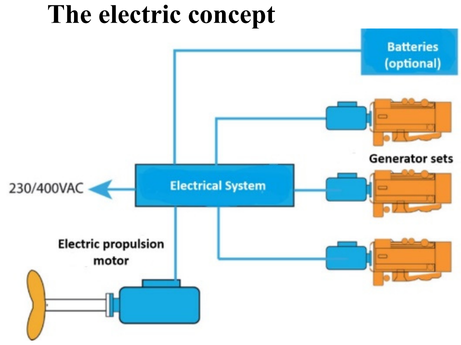

Fig.4. The electric concept skematic

The generators power the electric motor that propels the boat in all cases.

ADVANTAGES: space saving in the engine room and less maintenance.

All concepts can also be designed with batteries, in case the operational profile or the contract of the vessel requires it.

2.1. COMPARISON OF THERMAL /HYBRID SOLUTION

The hybrid solution allows space savings in the engine room as shown in the comparison below.

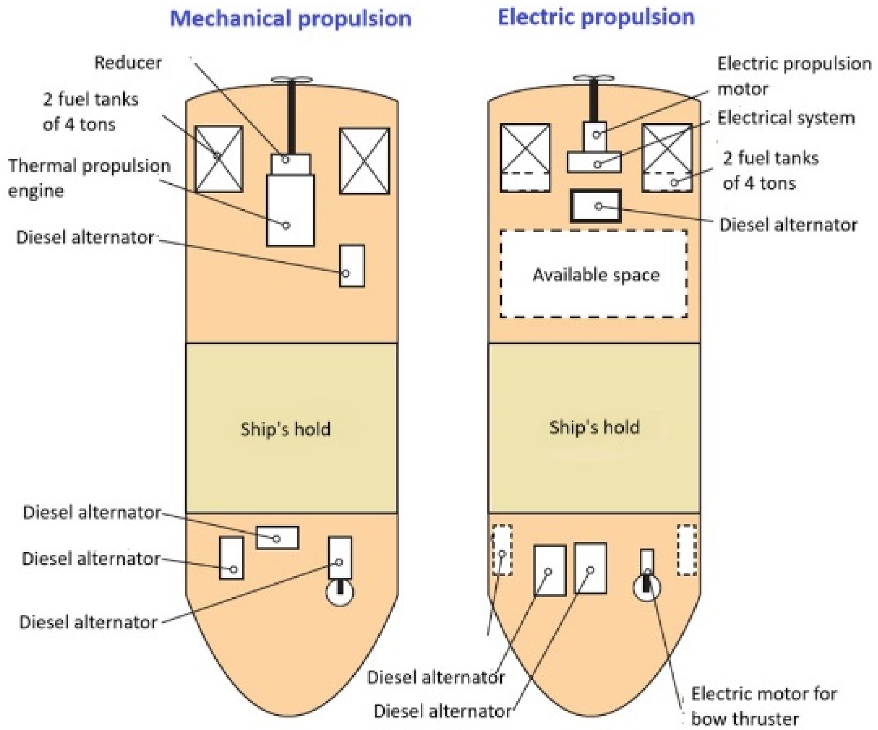

Fig.5. Components of mechanical/electric propulsion systems

Table 2. Comparison Thermal/Electric propulsion systems

Comparison criteria	Thermal propulsion	Electric propulsion
COMPONENT SIZE		-30%
SURFACE		-7%
MASS	-1%	
COST	-19%	
FUEL CONSUMPTION:		
Manoeuvring		-17%
Engine load 20%		-41%
Engine load 35%		-23%
Engine load 50%		-17%
Engine load 65%		-9%
Worst conditions	-4%	

The additional cost of installing a hybrid solution compared to a thermal engine is offset by fuel savings. These consumption gains vary according to the engine load: they will be more significant during the boat's manoeuvring phase.

The opportunity to study electric solutions is all the greater as the share of manoeuvres in the operating cycles of the unit concerned is significant.

Electric propulsion offers many advantages for river boats.

Economical

• Operating savings.

• Savings on maintenance costs.

• Fuel savings thanks to better engine load.

Operation / navigation

• Propulsion performance and propeller protection.

• Torque available at low speed.

• Propeller protection in the event of impact.

• Propeller stall protection.

• Increased comfort (noise, heat, and vibrations).

• Freely configurable weight distribution between the front and rear.

• Torque limitation in the channel.

• No cavitation in propeller operation.

• 230VAC/400VAC shore supply possible in the long term.

• Reduction of propeller cavitation, overload protection, and stall protection.

Ship instrumentation

• Power control (instead of speed control).

• Precise measurement data.

• Bow thruster power control possible.

• Power control (automatic and manual).

Environmental

• Emission reduction.

• Ability to meet contracts with environmental requirements.

• Battery use in emission-free zones.

Ship layout

• Weight is well distributed between the front and rear sections.

• Reduction gears can be removed.

• Possibility to use the engine room space for crew / apartment.

Restrictions

Mechanical propulsion is limited to the single propulsion engine, while electric propulsion involves the supply of a complete system designed considering the dependencies between the various components: it is therefore strongly recommended to purchase the complete electrical system from the same supplier.

The components that can be installed are defined by the characteristics of the routes taken by the boat: thus, a sufficient pilot's foot will allow the implementation of more elaborate electric or hybrid designs.

The availability of cooling liquid or air is a second parameter. This also concerns water-cooled components, as they are often more compact.

The electric system increases the weight of the machine. This can be compensated by less fuel carried and/or a better design of the engine, which is normally lighter than the traditional engine.

In case batteries are included in the system, the design also involves providing space for the battery (20% of the installation) and safety elements (ventilation, battery temperature control, etc.).

Passenger safety must be considered a priority of the installation.

3. ELECTRIFYING TUGS: A GOOD IDEA?

Tugs provide a critical service for safe operations in ports and coastal areas. Reducing emissions through electrification helps meet climate and air quality goals.

Tugs are essential to the maritime industry and are found in ports and coastal areas around the world. One of the primary roles of tugs is to safely guide large vessels to or from a mooring site by pulling on strong ropes attached to the vessel or pushing against the vessel's hull. Larger tugs escort oil tankers from the open sea to port to provide an extra measure of safety in the event the vessel loses propulsion or its rudder fails. These tasks require tugs to be powerful and manoeuvrable.

Fig.6. Tugboats in operation. (Source: Seaspan)

Despite the relatively small size of tugs, their powerful propulsion systems allow them to exert enormous force. Traditionally, tugs have used diesel engines because of their power and reliability. However, these engines emit significant amounts of greenhouse gases (GHGs) and other air pollutants that are harmful to the environment. As air pollution is reduced and shipping is decarbonized, there is growing interest in electrification. HaiSea Marine and SAAM Towage are two leading Canadian tug operators.

There are currently two types of electric tugs available: all-electric tugs and hybrid tugs. In the case of all-electric tugs, power is supplied by a battery that is recharged by plugging in to the shore, much like an electric car. All-electric tugs often have an onboard generator that can be used in an emergency. Limitations on battery range mean that all-electric tugs are optimal for short distances, such as port operations. For tugs that require greater range, hybrid tugs combine engines with battery-electric propulsion, allowing them to access either form of power, increasing their range while reducing overall fuel consumption. Their use is not limited by battery range to ports or areas near ports.

Electric tugs help reduce the maritime industry's carbon footprint, contributing to global efforts to combat climate change, while also providing co-benefits in terms of reduced noise and fuel consumption.

4. HaiSea'S FIRST ALL-ELECTRIC TUGBOAT

A partnership at the forefront of marine innovation, HaiSea Marine is a joint venture majority-owned by the Haisla Nation in partnership with Seaspan ULC. The organization made headlines with the launch of all-electric tugboats in April 2023. This initiative not only highlights technological advancement, but also underscores the organization's commitment to Indigenous reconciliation and environmental awareness.

Fig.7. The HaiSea Wamis, arriving in the Port of Vancouver under the Lion's Gate Bridge, is the first of three all-electric tugs ordered by HaiSea Marine to service a new LNG export facility in Kitimat, B.C. (Source: Mike Savage, 21Stops)

Demonstrating its commitment to environmental responsibility, HaiSea Marine now has three ElectRA 2800 electric harbour tugs and two larger RAstar 4000-DF escort tugs that run on either liquefied natural gas (LNG) or diesel. The ElectRA 2800 has a bollard pull of approximately 70 tonnes, while the RAstar 4000-DF escort tug has a bollard pull of 100 tonnes and the ability to generate up to 200 tonnes of force, making it one of the most powerful tugs on Canada's west coast.

These tugs will play a crucial role in protecting vessel movement through vulnerable marine ecosystems. The three smaller electric tugs will assist LNG carriers in safely arriving and departing the LNG Canada terminal berth. The two largest escort tugs will accompany the LNG carriers from Triple Islands near Prince Rupert to the terminal via Douglas Channel and back.

4.1. BENEFITS OF ELECTRIC TUGS

Electric tugs reduce air pollution, fuel consumption, and noise. While HaiSea Marine was the first in Canada to introduce electric tugs, SAAM Towage has also acquired two tugs of the same design, designed by Canadian naval architect Robert Allan Limited, for use in the Port of Vancouver.

Electrification reduces greenhouse gas emissions and air pollutants, ensuring compliance with global standards. Hybrid tugs reduce emissions by 30 to 60 percent compared to conventional tugs. All-electric tugs produce zero emissions during voyages. If the electricity used to charge their batteries comes from entirely renewable sources (such as the BC Hydro grid), they can be a true zero-emission solution.

For example, the ElectRA 2800 series tugs used by HaiSea and SAAM are equipped with a 5,288 kWh battery, ten times the size of an electric car battery. These batteries were developed by Corvus Energy at its facility in Vancouver, British Columbia,. They are sized to allow the tug to perform regular operations using 100% of the battery's electrical energy. This avoids the production of particulate matter, sulfur oxides, and nitrogen oxides. Each tug reduces carbon dioxide equivalent emissions by an amount comparable to nearly 1,000 gasoline-powered cars per year.

Beyond reducing emissions, electric tugs contribute to marine conservation goals by operating more quietly, without the engine vibrations produced by conventional tugs. The constant noise from maritime operations impacts the ability of marine species to communicate, find food, and reproduce. Electrifying tugs also reduce noise for the benefit of the crew.

These benefits demonstrate that electrifying tugs can reduce the environmental impact of the maritime industry.

4.2. LIMITATIONS OF CURRENT ELECTRIC TUGS

The emergence of electric tugs is an exciting development in maritime technology, but the transition is not an easy one.

The most obvious barrier is the initial investment required for electric tugs. These vessels are typically more expensive – 50% more – than their traditional counterparts due to the high cost of electric propulsion systems. These costs include not only the vessel itself but also the infrastructure needed for charging and maintenance. In addition, the lack of widespread adoption means few economies of scale to reduce costs. Shipowners must weigh these initial costs against the long-term benefits, such as energy savings and reduced fuel costs.

Fig.8. Generators on board of HaiSea Wamis (Credit: Clear Seas)

In addition, the size and weight of the batteries pose design challenges. Batteries must be accommodated without compromising the functionality of the tug, including space for crew and necessary equipment. Designers must find a balance to accommodate the electric propulsion system without affecting the versatility and operational efficiency of the tug.

Fig.9. A battery group on board of HaiSea Wamis (Credit: Clear Seas)

Fig.10. One of two battery groups on the HaiSea Wamis (Credit: Clear Seas)

Fires caused by lithium-ion batteries in consumer devices have raised concerns about their safety. Lithium-ion batteries store a large amount of energy in a small space, giving them a high energy density. However, this also means that if a battery cell is damaged or improperly charged, it can cause a large amount of energy to be released in an uncontrolled manner, commonly known as thermal runaway, where the internal components of the cell break down and release gases that can ignite if exposed to oxygen. In the confined space of a ship's hold, this could be catastrophic.

Fortunately, the battery's designers use a system called single-cell passive thermal runaway protection meaning that even if one of the battery cells goes into thermal runaway, the damage will not spread to the other cells. Other measures to ensure safety include training staff on how to handle batteries safely and how to identify and remove damaged batteries. Operators are committed to safe operations and regularly review systems to identify and respond to potential hazards.

5. CONCLUDING REMARKS

Electric propulsion for river ships is no longer just a concept; it's becoming a reality thanks to advancements in battery technology, electric motors, and infrastructure. This shift is crucial for reducing emissions, lowering operational costs, and minimizing noise pollution. The gradual adoption of hybrid systems and regulatory support further aids this transition. As technology evolves, we'll likely see even more efficient, cost-effective, and environmentally friendly river ships navigating our waterways.

The prioritization of several key measures will promote the production of a greater number of electric tugs.

First, accessible charging infrastructure is essential. As the number of electric vessels increases, ports need to be equipped with high-capacity charging stations to allow for quick stops and minimal disruption to operations. Governments and port authorities can provide incentives for the installation of charging stations. One example is the funding provided by the Government of Canada to support the installation of shore power technology for cruise ships and container ships in Canadian ports.

Furthermore, innovations in battery technology could lead to more energy-dense solutions, reducing the size and weight of batteries and increasing the number of vessels in which all-electric propulsion systems are possible. Continued technological advances will play a crucial role in overcoming the current limitations of electric tugs to make the electrification of all tugs a more viable option for the entire maritime industry.

Electric tugs represent a shift towards a more sustainable maritime industry. With ports setting zero-emission targets in the future, there will be opportunities for electric-powered tugs. Despite the challenges associated with their adoption, the long-term benefits to the environment, operational costs, and crew well-being make them a worthwhile investment. HaiSea's investment in battery-electric tugs provides a case study for the application of these technologies. As technology evolves and regulatory frameworks adapt, electric tugs are likely to become increasingly common in ports around the world.

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