Gulf Marine

Technical Brief

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Supporting Operational Efficiency and Environmental Goals

Author: *Irwan Jaafar, Vincent Ang, Chan ChaoXiang, Obydur Rahman, Junrong Lim*

[Published in Apr 2026] TB031

Facing urgent sustainability goals, the marine industry requires solutions that reduce waste and emissions without compromising operational integrity. Re-refined base oils (RRBO) address this challenge by recovering up to 80% of base oil from used lubricants through advanced processes like solvent extraction and hydrotreating. This significantly reduces demand for virgin oil production and minimises environmental impact of waste disposal, offering a direct path towards circular economy principles in lubrication.

This technical brief evaluates RRBO as a sustainable alternative for marine cylinder lubricants. Comprehensive laboratory testing and extensive 4,000-hour real-world engine trials demonstrated that marine lubricants with up to 20% RRBO performed comparably to traditional virgin-based formulations in deposit control and oxidation resistance. Scavenge port inspections and carbon measurements revealed no abnormalities in lubricant performance, solidifying RRBO as a reliable and environmentally responsible component for future marine lubricants.

The Drive for Sustainable Lubrication

The shipping industry faces increasing pressure towards maritime decarbonisation, underpinned by regulatory frameworks such as IMO Revised GHG Strategy targeting net-zero emissions by 2050.

Lubricants, typically comprising 80–90% base oils by volume, represent a significant lever for reducing lifecycle emissions. Re-refined base oils (RRBOs) are produced via advanced processes such as vacuum distillation, hydrotreating, clay treatment, and solvent extraction, delivering base oils that can reach API Group II quality. Concurrently, the persistent challenge of used lubricants disposal, where over 40% is managed improperly globally, underscores the urgent need for sustainable solutions.

Life cycle analysis indicates that RRBO can achieve up to 81% lower CO_2 emissions compared to virgin oils, with industry insights suggesting potential savings of up to 85–90%.

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Re-refining also requires 50–80% less energy than crude refining.

Peformance Evaluation Objectives

Building on the industry needs for sustainable alternatives, this technical brief details a performance evaluation of marine cylinder oils formulated with RRBO. The primary objective was to assess the feasibility of substituting 5–20% of virgin base oil with RRBO substitution without compromising critical performance parameters.

The investigation employed a two-phase approach: first, laboratory bench tests, including Komatsu Hot Tube Test (KHT), Panel Coker Test (PCT), and Pressure Differential Scanning Calorimetry (PDSC), to assess deposit control and oxidative stability; second, an engine trial to validate these findings under real-world operating conditions.

The results are discussed in the context of sustainability benefits, including lifecycle CO_2 reduction and industry alignment with alternative fuel pathways.

Re-refining: From Waste to Resource

The transformation of used lubricating oils into high-quality RRBO is achieved through advanced re-refining, a process distinct from basic recycling. It begins with the collection of waste lubricating oils, followed by impurity removal.

The core techniques include:

- Vacuum Distillation
- Hydrotreating
- Clay Treatment
- Solvent Extraction

Compared to refining crude oil into virgin base oils, re-refining is less energy intensive, resulting in lower CO_2 emissions. RRBOs can meet API Group II specifications when processed with advanced hydrotreating.

Table 1 Typical data of re-refined vs virgin base oil (SN150).

Property	Unit	Re-refined base oil	Virgin base oil
Viscosity @ 40 °C	mm²/s	29 – 32	29 – 31
Viscosity Index	–	105 – 115	95 – 100
Colour	–	L 0.5	L 1.0
Sulphur	ppm	10 – 2000	2000 – 6000
Total Acid Number (TAN)	mg KOH/g	< 0.03	< 0.05
Vapour Loss (Noack)	wt.%	8 – 12	12 – 16
Polycyclic Aromatic Comp. (PAC)	wt.%	< 0.2	< 1.0

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Performance Validation: From Laboratory to Sea Trial

To confirm the suitability of RRBO in demanding marine environments, Gulf Marine designed and executed a comprehensive evaluation programme encompassing both laboratory bench tests and sea trials.

During the initial experience-gathering study, marine cylinder oils were identified as a suitable application for RRBO due to their total-loss lubrication system. In this system, the lubricant is fully consumed during engine operation rather than being recirculated. This approach minimises the risk of performance impact during operation.

Laboratory Bench Tests

Three industry-recognised tests were employed:

i. **Komatsu Hot Tube (KHT)**: evaluates high-temperature varnish and deposit tendency.

ii. **Panel Coker Test (PCT)**: measures coking and varnish deposits under thermal cycling.

iii. **Pressure Differential Scanning Calorimetry (PDSC)**: determines oxidation induction time under pressurised oxygen at high temperature.

Formulations containing 5–20% RRBO were benchmarked against baseline virgin base oil formulations.

Engine Trial Setup

The engine trial was conducted in close collaboration with OEMs and vessel operators. The trial vessel was selected based on engine type, typical sailing profile, and maintenance history. To enable a parallel comparison between virgin-based and RRBO-based cylinder oils, a split lubrication system was installed. This setup allowed the RRBO-based lubricant to be introduced under controlled conditions and evaluated directly against a virgin-based cylinder oil.

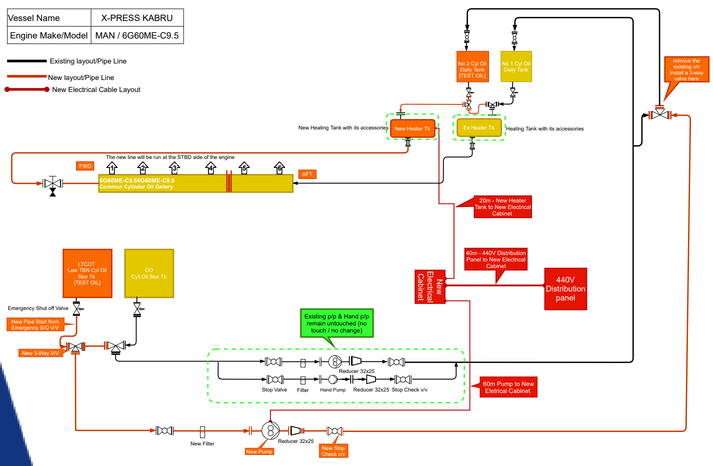


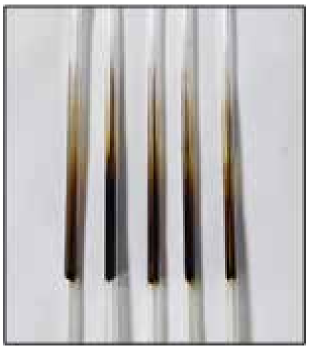
Fig. 1 Schematic diagram of the engine trial split-lubrication system for comparative evaluation of virgin-based and RRBO-based cylinder oils.

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Results and Findings

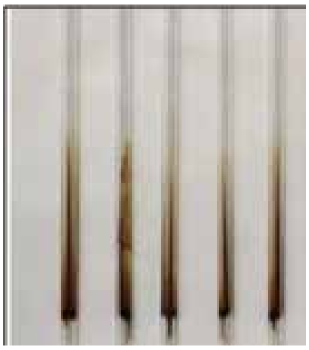
Komatsu Hot Tube Test: The KHT test results showed that formulations containing up to 20% RRBO performed comparably to virgin base oil formulations.

Panel Coker Test: Panel Coker tests indicated that deposit formation with up to 20% RRBO substitution remained within acceptable ranges.

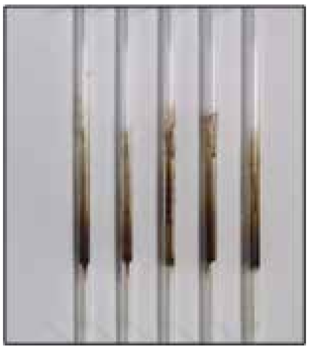


a. XP 5040 (Virgin Base Oil)

b. XP 5040 (10% RRBO-A)



c. XP 5040 (20% RRBO-B)



d. XP 5040 (20% RRBO-C)

Fig. 2 Komatsu Hot Tube (KHT) test results comparing deposit formation for XP 5040 formulations with virgin base oil and RRBO blends.

a. XP 5040 (Virgin Base Oil)

b. XP 5040 (10% RRBO-A)

c. XP 5040 (20% RRBO-B)

d. XP 5040 (20% RRBO-C)

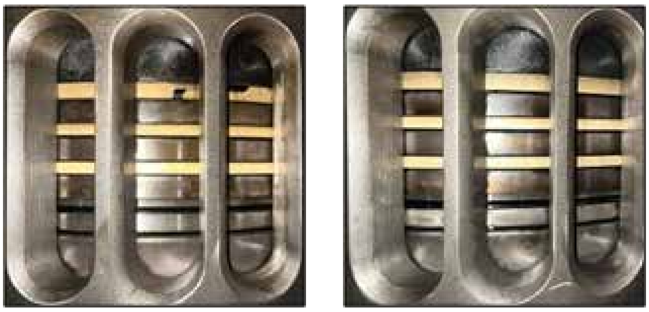
Fig. 3 Panel Coker Test (PCT) results comparing deposit formation for XP 5040 formulations with virgin base oil and RRBO blends.

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Oxidation Stability (PDSC): PDSC results demonstrated equal or longer oxidation induction times for RRBO-based formulations up to 20% substitution.

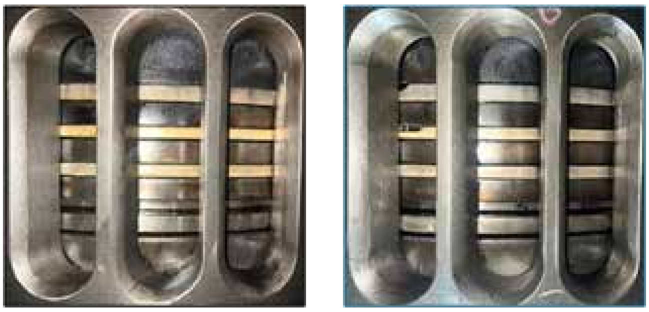
Fig. 4 PDSC results comparing oxidation stability of XP 5040 formulations with virgin base oil and RRBO blends.

Field Engine Trial: An engine field test was conducted for nearly 4,000 hours using GulfSea Cylcare XP 5040 (XP 5040) formulated with virgin base oil and, in parallel, XP 5040 containing a 20% RRBO blend in a slow-speed marine engine. Inspections revealed no abnormal deposits, and the overall performance of the 20% RRBO-based formulation was consistent with and comparable to that of the virgin base oil formulation.



a. XP 5040 (No RRBO)   b. XP 5040 (20% RRBO)

Fig. 5 Piston condition after 512 hours of operation with XP 5040 formulations using virgin base oil and a 20% RRBO blend.

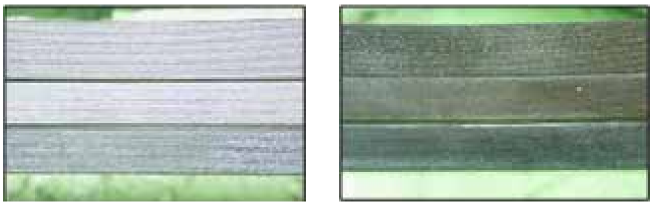


a. XP 5040 (No RRBO)   b. XP 5040 (20% RRBO)

Fig. 6 Piston condition after 2513 hours of operation with XP 5040 formulations using virgin base oil and a 20% RRBO blend.

a. XP 5040 (No RRBO)   b. XP 5040 (20% RRBO)

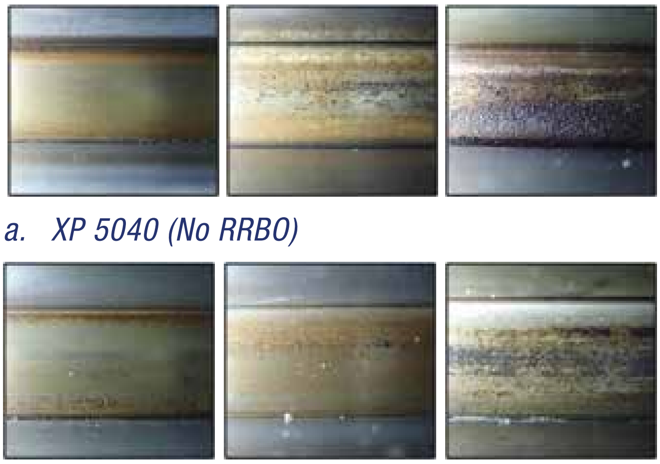
Fig. 7 Piston condition after 3891 hours of operation with XP 5040 formulations using virgin base oil and a 20% RRBO blend.



a. XP 5040 (No RRBO)   b. XP 5040 (20% RRBO)

Fig. 8 Back of the piston ring condition after 3891 hours of operation with XP 5040 formulations using virgin base oil and a 20% RRBO blend.

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)



a. *XP 5040 (No RRBO)*

b. *XP 5040 (20% RRBO) - Piston ring Grooves*

Fig. 9 Piston ring groove condition after 3891 hours of op-eration with XP 5040 formulations using virgin base oil and a 20% RRBO blend.

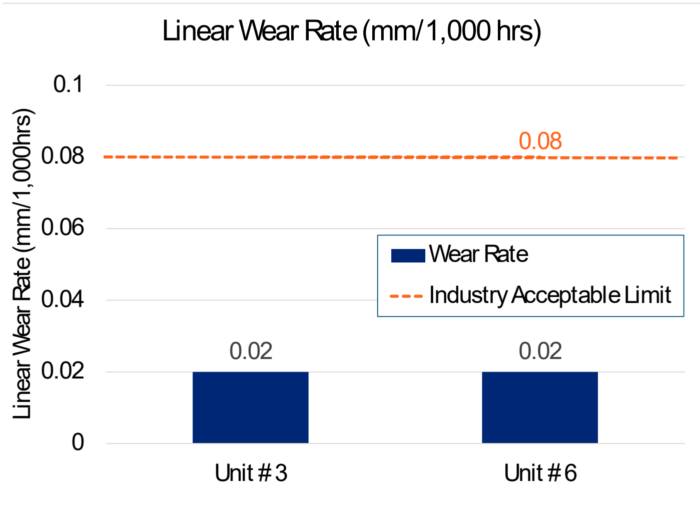


Fig. 10 Comparison of linear wear rates for virgin-based (Unit #6) and RRBO-based (Unit #3) formulations, both at 0.02 mm/1,000 hours, confirming that the RRBO blend delivers performance consistent with the virgin base oil.

Consistency Between Laboratory and Sea Trial Data

The results from the 4,000-hour engine trial strongly corroborated the laboratory findings that up to 20%RRBO substitution does not compromise lubricant performance. Deposit control and oxidation stability were comparable to virgin base oil formulations. RRBO adoption supports the maritime industry's sustainability goals, with life-cycle assessments estimate greenhouse gas savings of 7,500 metric tons per million gallons of lubricants produced.

Peer-reviewed studies confirm that RRBO offers an 81% lower CO_2 footprint compared to virgin base oils, and industrial insights show potential reductions up to 90%. Recent reviews also emphasise that waste oil recycling and re-refining pathways are both technologically and economically feasible. Market analyses highlight that re-refining is an increasingly important part of the lubricant industry, rebounding after the pandemic. These findings align with broader industry initiatives, including CIMAC's recognition of lubricants as enablers of alternative fuels and decarbonisation pathways.

Advancing Lubricant Sustainability with Re-Refined Base Oils (RRBO)

Conclusion and Industry Outlook

This study, through laboratory testing and field engine trials, comprehensively validates the technical feasibility of integrating Re-Refined Base Oils (RRBO) into marine cylinder lubricants at substitution levels of up to 20%. RRBO-containing formulations demonstrated performance parity with virgin base oil formulations in deposit control and oxidation stability.

The adoption of RRBO offers the maritime industry a practical path that balances operational reliability with environmental responsibility. It represents a proactive response to the IMO 2050 strategy and aligns with the role of lubricants as enablers for alternative fuels and decarbonisation pathways.

Looking ahead, Gulf Marine will continue to explore the potential for higher RRBO incorporation rates and extend its evaluation to other lubricant product families, persistently providing innovative, efficient, and sustainable lubrication solutions to the global fleet, jointly navigating the maritime industry towards a decarbonisation future.

- END-