Challenges in Managing Mercury in Field Development and Production

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Integrating Produced Water Reinjection, Partitioning Chemicals and Recovery Pathways for Sustainable Mercury Management in Malaysia's Upstream Ecosystem

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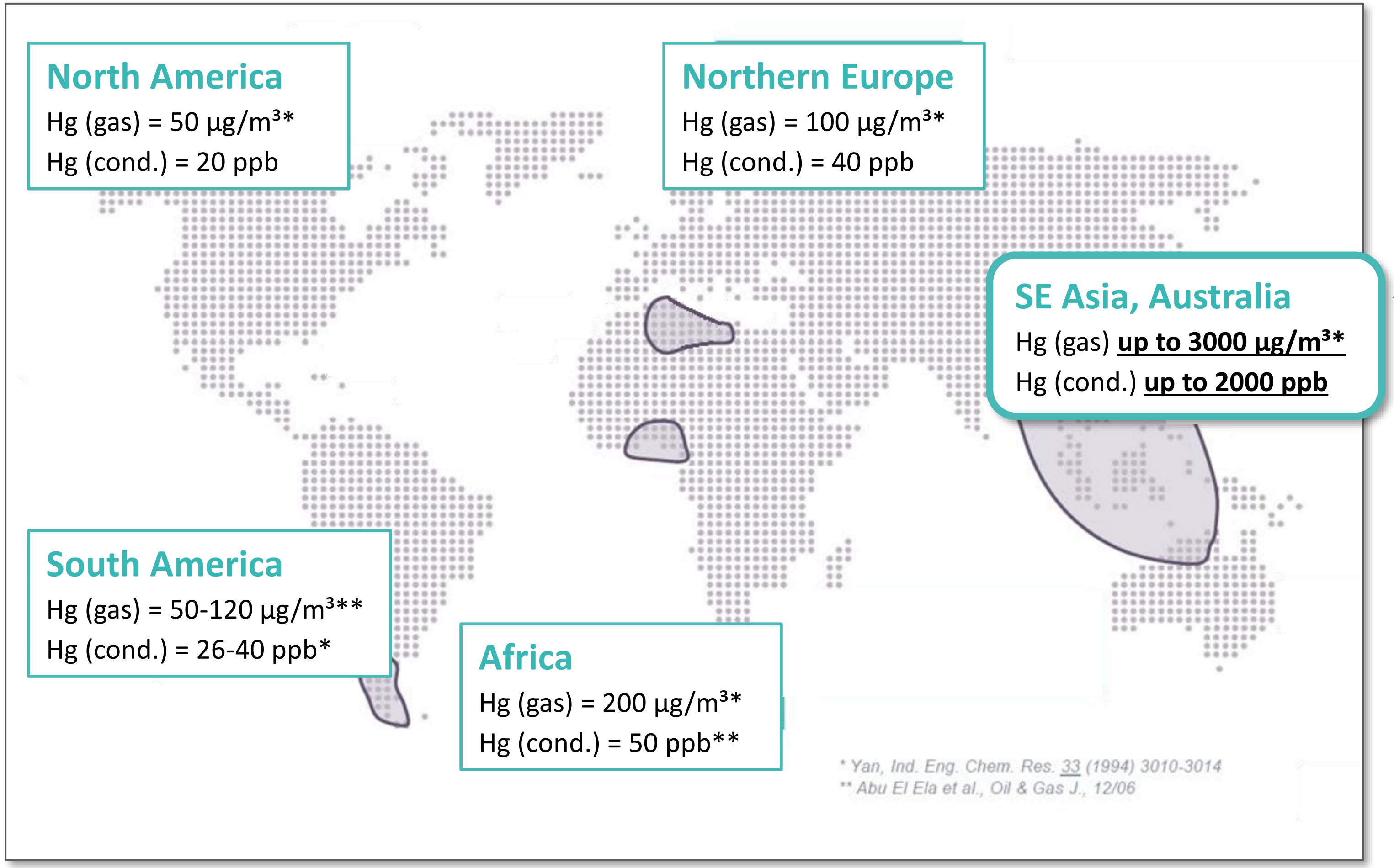
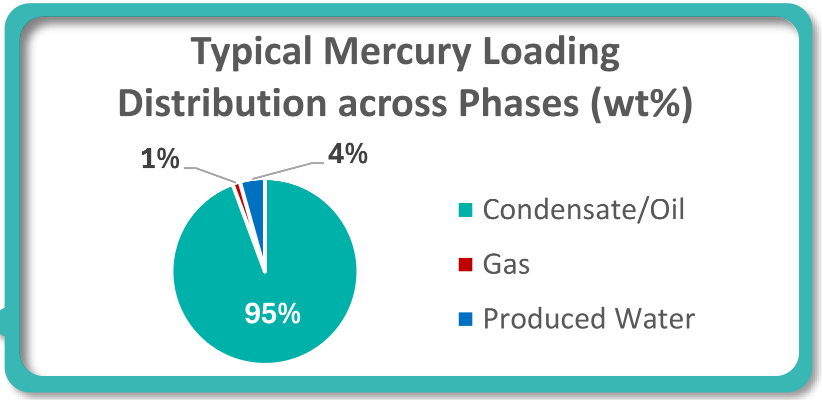
Mercury (Hg.) presence in hydrocarbon reserves is a global occurrence with typical concentration levels particularly significant in the South East Asia – Australia region



Source: How to Remove Mercury from Extracted Natural Gas? <https://blog.axens.net/how-to-remove-mercury-from-extracted-natural-gas>



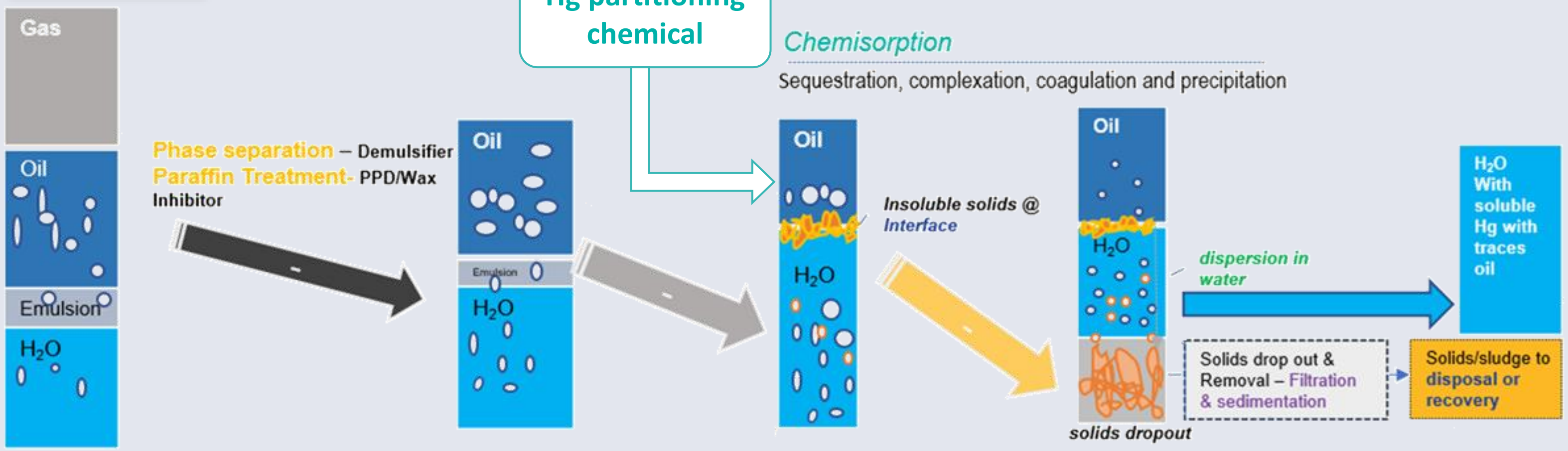
1. Of the liquid phases, Hg. partitions preferentially into the cond./oil phase.

2. However, design of mercury removal unit (MRU) during development stage is challenging due to speciation uncertainty.

3. Furthermore, data from exploration wells may not be representative due to short well test windows or sampling issues.

Chemical partitioning applications are proven effective in shifting mercury to aqueous or insoluble phases, enabling more options for managing mercury found in oils/condensates

Concept



Laboratory Simulation Result

100 ppm — Optimum Injection Dosage

15 – 240 minutes — Retention Time (Designable)

0.2 – 61.0 µm — Particle Size Distribution in Water Post Treatment

87 – 93% — Total Hg Reduction in Condensate

128 – 702% — Total Hg Increment in Water Phase

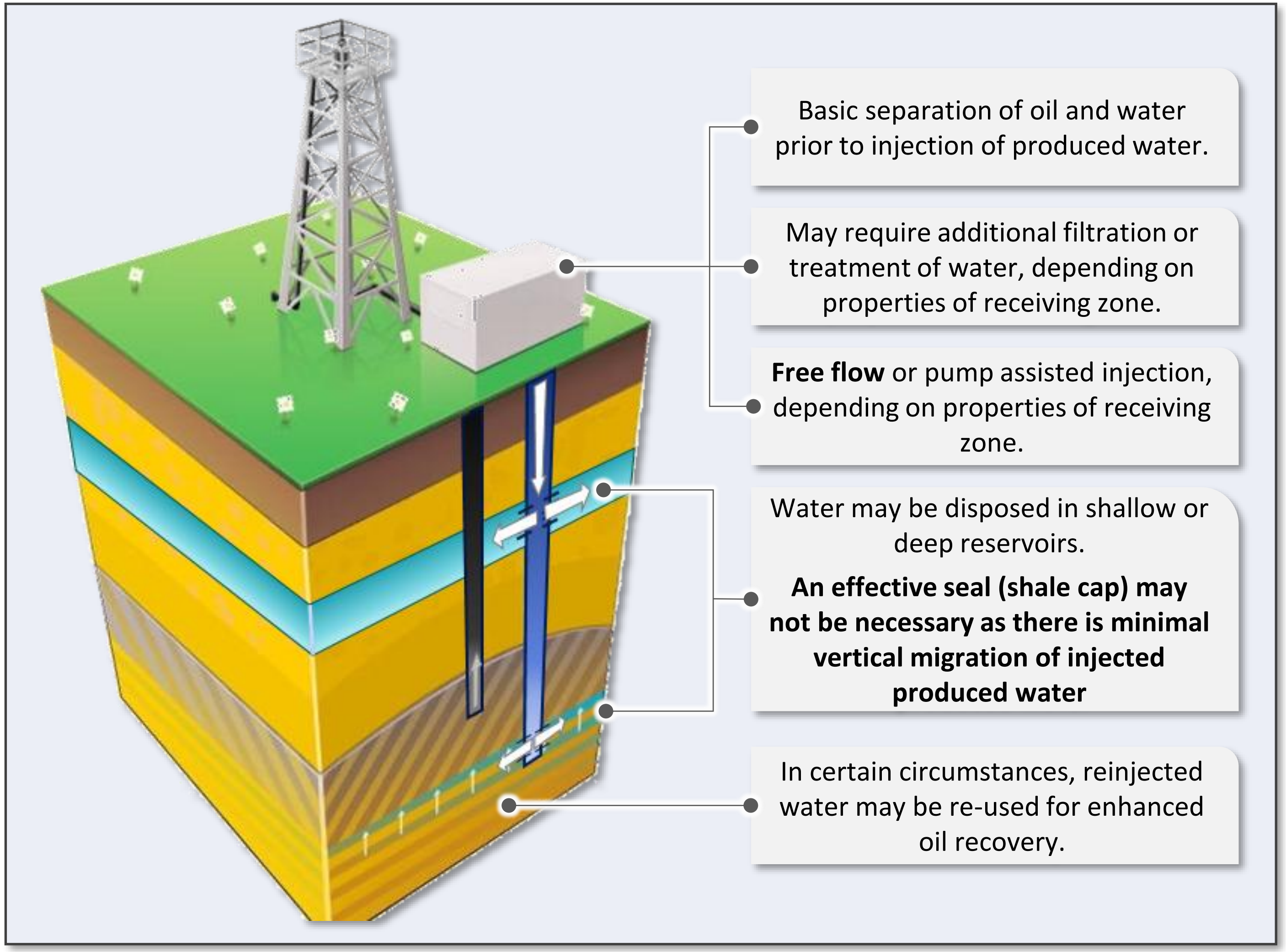
25 – 75% — Workable Range of Water Cut

1. Mercury partitioning presents a theoretically cost-efficient approach for managing mercury concentrations in the range of 100 to 5,000 ppb.

2. This method offers a potential alternative to conventional MRUs at facilities, with an estimated cost optimization of up to 90%.

3. It also helps prevent the bulk transport of mercury in crude or condensate to shore, thereby enhancing operational safety and compliance.

Complementing chemical partitioning, Produced Water Reinjection (PWRI) presents a pathway for mercury sequestration while managing produced water directly at the source

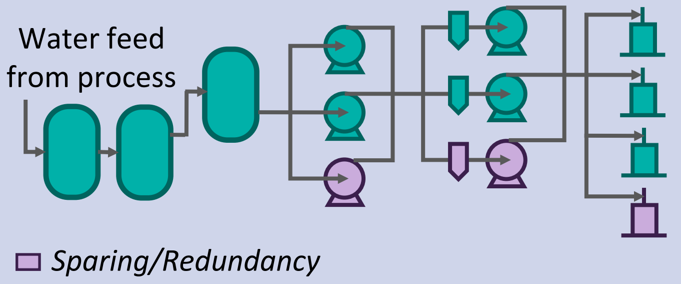
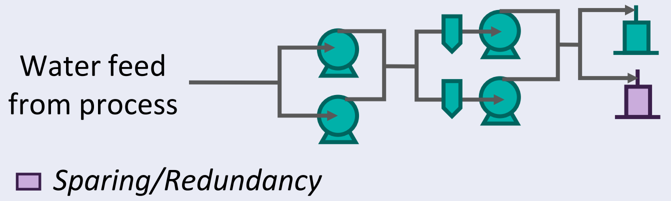


1. PWRI are engineered systems designed to return produced water back into the geological formations, effectively isolating contaminants from the surface environment.

2. PWRI can be categorized into two subtypes based on site suitability: simple water disposal wells (WDW) and reinjection wells used for production pressure maintenance. Both approaches offer long-term containment with minimal operational requirements, making them a lower-maintenance alternative to conventional water management systems.

3. PWRI is considered an environmentally superior alternative to surface discharge or treatment, as it minimizes surface footprint, reduces emissions, and mitigates the risk of contaminants entering the ecosystem.

When conditions at individual facilities are favourable, PWRI systems can be simplified to provide a cost-effective solution that optimizes both performance and costs

Complexity	Typical Specifications	
Full Specification: Selected when produced water volume is high, or disposal zone properties demand powerful reinjection. Required for complex disposal zones with pressure challenges or low injectivity.	**Water flowrate and Injection Pressure:** >30 kb/d, ~60 barg **Equipment:** • 2x hydrocyclones • 2x Booster Pumps • 2x Cartridge Filters • 1x Degassing drum • 2x Injection Pumps • 3-4x Disposal Wells Back-up: 2x pumps and 1x well and/or PWTS (overboard)	
Intermediate: Possible when water volumes are moderate, and the disposal zone has moderate injectivity.	**Water flowrate and Injection Pressure:** ~20 kb/d, ~20 barg **Additional equipment:** • 2x Booster Pumps • 2x Cartridge Filters • 2x Injection Pumps • 1x Disposal Wells Back-up: 1x well and/or PWTS (overboard)	
Fit-for-purpose: Possible when below criteria are met: ☑ low water rates ☑ low particle size ☑ high injectivity disposal zone	**Water flowrate and Injection Pressure:** <10 kb/d, ~15 barg **Additional equipment:** • Piping and connection • 1x Disposal well Back-up: PWTS (overboard)	

1. Not all reinjection systems need to be complex.
2. Assessing site-specific factors such as water volume, particle size, and reservoir injectivity allows operators to right-size reinjection solutions, avoiding unnecessary overengineering and reducing both capital and operational expenditure.
3. Fit-for-purpose designs offer a smart alternative, especially in facilities with low water production and favourable geology.

A brownfield case study shows that implementation of PWRI with chemical partitioning results in a cost-effective and sustainable approach to water and mercury management

	Mercury Recovery Unit	Conventional Water Disposal Well	Fit-for purpose Water Disposal Well
Injectivity of target reservoir	N/A	Low- Moderate	High (Shallow Sand)
Reinjected water quality	N/A	**Stringent:** **OIW**: <50 ppm, **TSS**: <50 mg/L, **PSD**: <5 µm	**Relaxed** **OIW**: <2500 ppm, **TSS**: <50 mg/L **PSD**: 20 µm (Dv50), 100 µm (Dv90)
Surface equipment	Particulate filtration MRU for condensate	2x Filter Feed Pumps, 2x Cartridge Filter, 2x Injection Pumps, Associated piping	Valves and associated piping
Est. CAPEX	**TOTAL: USD 29.6 Mil**	**Surface**: USD 42.0 Million **Subsurface**: USD 34.6 Million (new well) **TOTAL: USD 76.6 Million**	**Surface**: USD 1.6 Million **Subsurface**: USD 1.9 Million (well conversion) **TOTAL: USD 3.5 Million**
Est. OPEX	**Filter replacement:** USD 100k/year **Waste management:** USD 15k/year **Utilities/Consumables:** USD 20k/year **Maint. & logistics:** USD 60k/year **TOTAL: USD 195k/year**	**Chemical:** USD 115k/year **Surface O&M:** USD 115k/year **Fuel gas:** USD 400k/year **TOTAL: USD 630k/year**	**Chemical:** USD 20k/year **Surface O&M:** USD 10k/year (mainly for routine inspection) **Subsurface O&M:** USD 70k/year **TOTAL: USD 100k/year**

1. Identifying a high injectivity reservoir for PWRI can unlock significant savings without compromising reliability and asset integrity.
2. A well-placed, converted disposal well can deliver over 95% cost avoidance in both CAPEX and OPEX.
3. PWRI supports not just mercury management but also optimizes overall produced water handling strategies.

Moving forward and in line with PETRONAS' Governing Standards, the evaluation of a 100% PWRI design will be a requirement for all future offshore developments in Malaysia

Governance Documents

PETRONAS GUIDELINES ON MINIMUM ENVIRONMENTAL SPECIFICATIONS

MY ALL X X S 09 075 I
PETRONAS CARIGALI SDN BHD (PCSB)
WASTEWATER MANAGEMENT PROCEDURE

Revision 0

Feasibility Of 100% PWRI For New Offshore Facilities To Be Evaluated

Evaluation Parameters

Produced Water Rates
Estimate water production forecast for each development concept

Produced Water Specifications
Estimate parameters and quality of produced water including contaminants such as mercury

Shallow and Deep Aquifers
Evaluate presence, size, storage capacity, injectivity, containment in relation to produced water rates (number of injector wells required)

PWRI for Improved/Enhanced Oil Recovery
Evaluate target reservoir, IOR gain, capacity, injectivity, containment in relation to produced water rates (number of injector wells required)

1. Existing governance documents have been enhanced to make PWRI the new standard if justified by techno-commercial assessments.
2. Produced water will be assessed for IOR/EOR or for straightforward disposal into high-injectivity formations.
3. Incorporating PWRI from the design stage enables maximum economic value while optimizing operational efficiency and minimizing environmental impact over the project lifecycle.

To complete the circular approach, residual recovery allows any remaining mercury reaching downstream to be recovered, creating value while minimizing environmental impact

Control at Source

PWRI with mercury partitioning / agglomeration chemicals

Residual Recovery

Mercury arriving onshore to be recovered for reutilization in other industries

Mercury contaminated scheduled wastes to be sent to 3R facilities

Value Creation

(per facility, vs. conventional method / linear economy)

CAPEX
Up to ~90% lower

OPEX
Up to ~50% lower

Waste
Up to 30 tons lower

1. Adopting a circular approach to mercury management future-proofs developments in high-contaminant basins and fields, where conventional removal strategies may not be technically or economically viable.

2. It also enables operators to stay ahead of tightening environmental regulations, embedding compliance-readiness and sustainability into the early phases of project planning.

3. Together, these advantages create an end-to-end mercury management framework that optimizes cost, compliance and the environment.

Summary and Conclusion

1. Mercury in oil and condensate reserves is a widespread issue, especially in Southeast Asia and Australia, and can be effectively managed at source through chemical partitioning which shifts mercury into the more controllable water or insoluble phases.

2. Produced water reinjection, when combined with chemical partitioning, offers a cost-effective, sustainable solution for water and mercury management—validated by a brownfield case study and aligned with PETRONAS' mandate to evaluate 100% PWRI for future offshore developments.

3. Residual recovery at downstream facilities completes the circular approach, capturing remaining mercury, reducing environmental impact, and reinforcing a closed-loop, value-driven mercury management strategy.

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