Oil and Water Shouldn’t Mix

RESTORATION OF STEAM TURBINE OIL DEMULSIBILITY

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STLE 2018, Minneapolis, MN

Matthew G. Hobbs, Ph.D., Peter Dufresne Jr., Min Joo Kim and Safeer Nanji

EPT, Calgary, AB, Canada

Who We Are

EPT specializes in lubricant treatment.

- 25 years experience.
- Lubricant Testing.
- Extensive R&D:
  - Advancing the science of lubricant management

Steam Turbines

- Convert rotational energy into useful work (electricity).
  - ST responsible for ~80% of power generation.
- Feature rotating shaft in a bearing.
- Lubricant:
  - Facilitate rotation.
  - Provide hydrodynamic lift.
    - Oil Wedge = 0.02 – 0.1 mm (1/2,500 – 1/250”).
- ST oils often contaminated with water.
  - Potential failure mode.
  - Downtime costly.

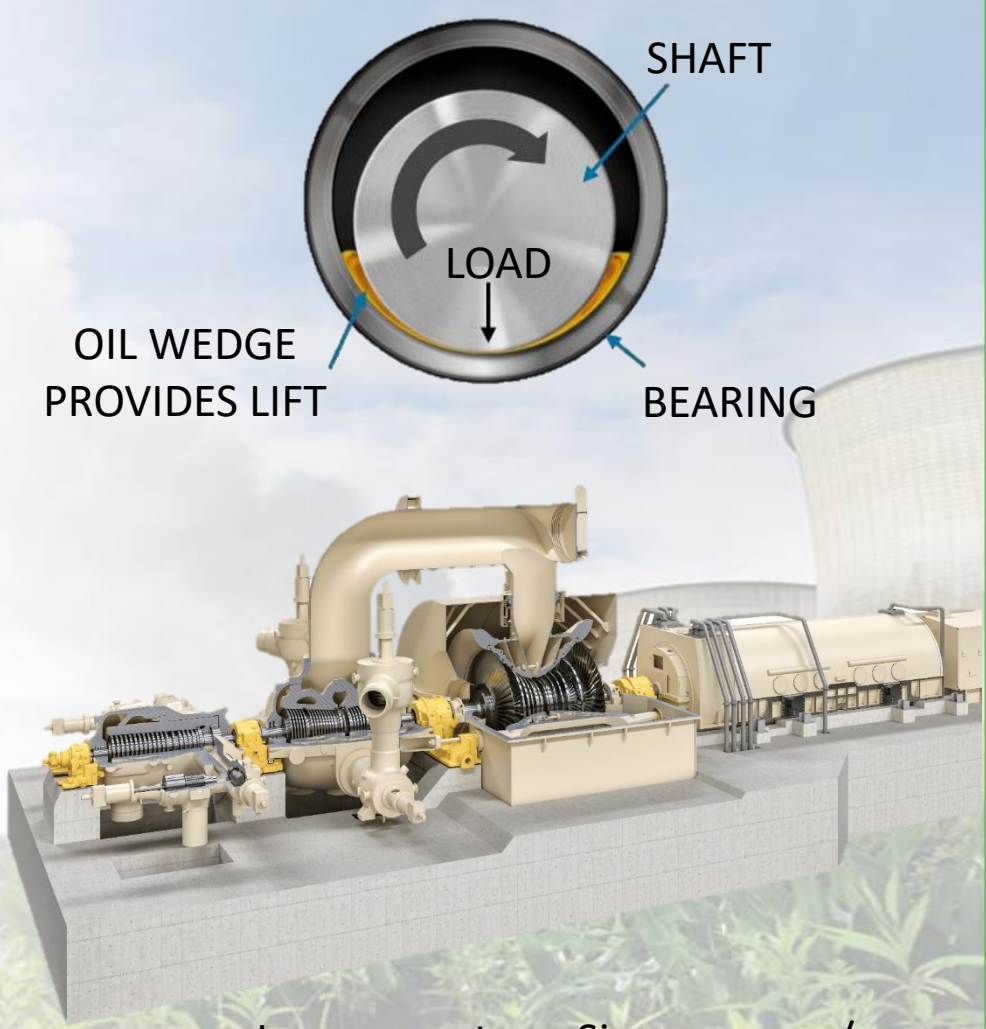


Image courtesy: Siemens.com/press

Water Contamination

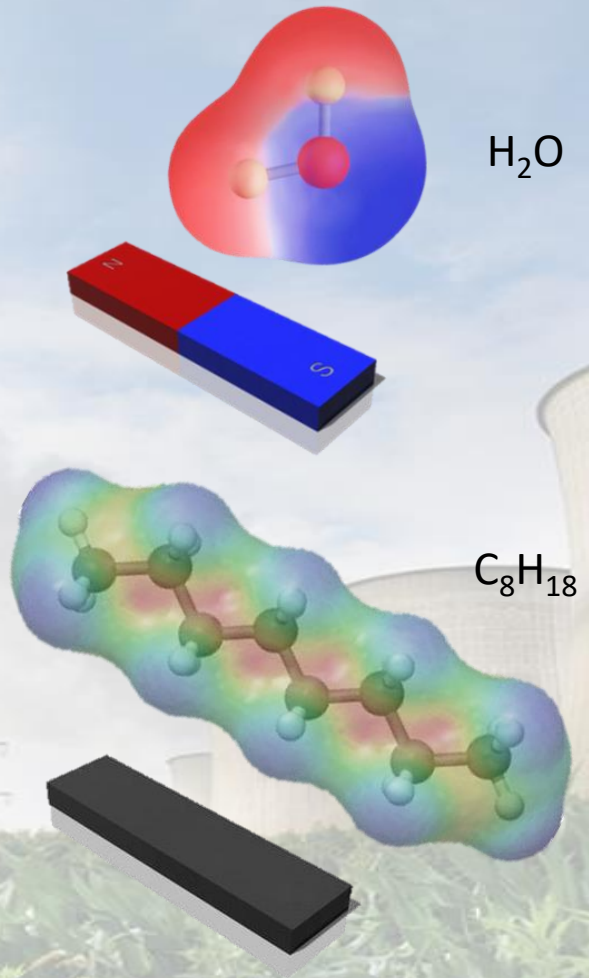
- "Oil and water don't mix."
- Clash of chemistries.
  - "Like dissolves like."

- Water is polar.
  - (+) end and (-) end.
  - Strong attractive intermolecular forces.

- Oils are non-polar.
  - Hydrocarbons have marginal charge separation.
  - Weaker intermolecular attractions.

- Oil cannot overcome attractive force between water molecules.

- Water in oil takes 3 forms.



H_2O

C_8H_{18}

Image courtesy: Molfield.org

1) Free Water

- Oil and water separate.
- Water more dense.
  - Forms layer below oil.
  - “Free water.”
- Free water can be extremely harmful.
  - Inadequate load-carrying capacity and lubrication ability.
  - Corrosive.
  - Promotes breakdown/additive dropout.
- Engineered solutions keep free water from critical components.
  - Gravity/centrifugal separation.
  - Oil suction.
  - Coalescers.

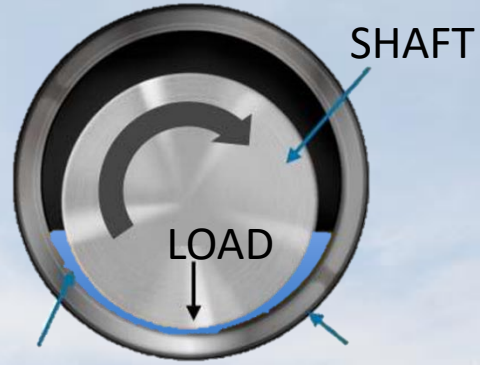


Image courtesy: EPRI

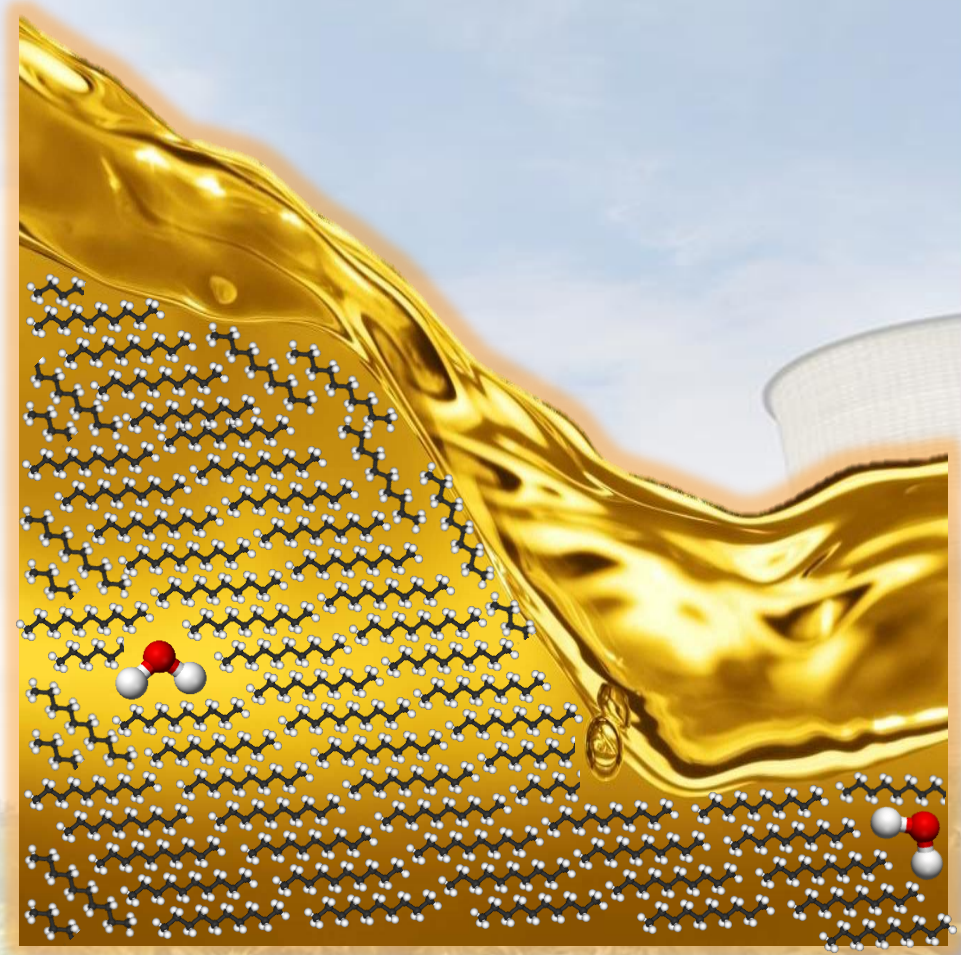
2) Dissolved Water

- Oil and water do mix … a little.

- Turbine oils have finite ability to dissolve water.
  - Varies with temperature and oil condition.
  - Typically ~100 ppm water.
  - Low H_2O concentration → H_2O statistically dispersed.

- Dissolved water:
  - Little impact on lubrication properties.
  - Promotes corrosion.
  - Promotes breakdown.

- Not as harmful as free water.
  - Oils should still be kept dry.



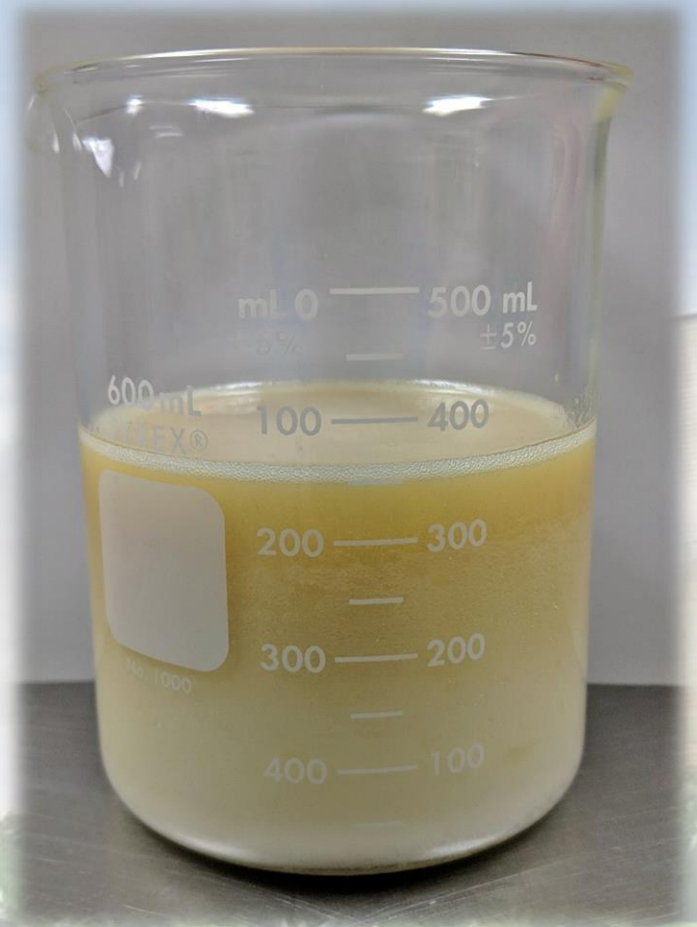
3) Emulsions

- Emulsion:
  - Formed by agitation of oil/water.
  - Fine dispersion of water drops suspended in oil.
  - “Cloudy” or “milky” appearance.

- New oils/oils in good condition:
  - Emulsions unstable and revert to separate layers.

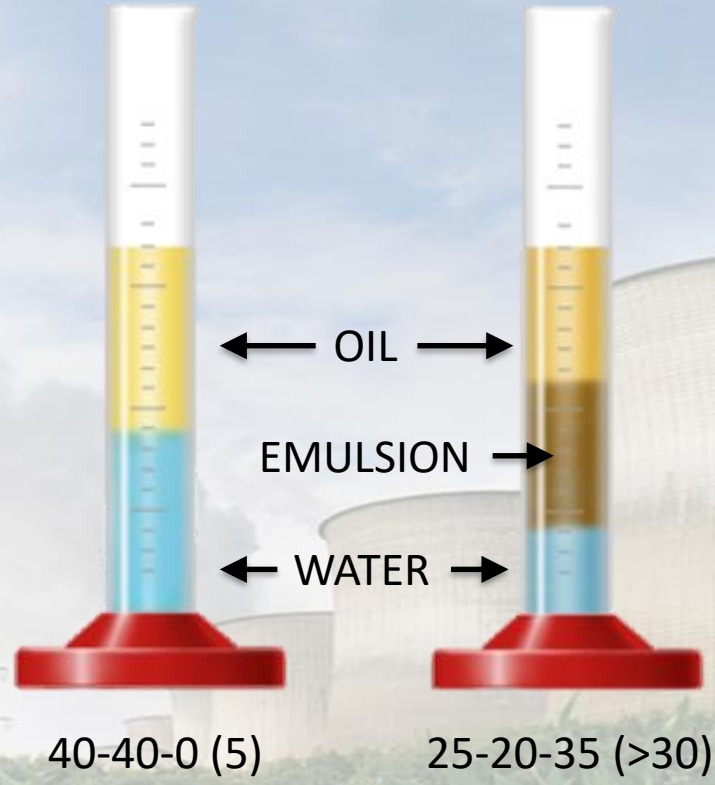
- Used oils:
  - Polar contaminants/breakdown products.
    - Enhance oil-water attraction (and disrupt H_2O-H_2O attraction).
    - Stabilize emulsions.

- Harmful in STs:
  - Cause similar problems to free water.
  - Cannot be easily removed.



Oil-Water Separability

- ASTM D1401: Industry standard test for demulsibility.
  - Measure tendency towards emulsion formation.
  - Measure time required for oil-water separation.
- 40 mL oil + 40 mL water mixed for 5 minutes.
- Oil-water separation monitored at 5 minute intervals thereafter.
  - Stop test when separation complete.
    OR
  - Stop test after 30 minutes if separation still incomplete.
- Result recorded as:
  - mL oil – mL water – mL emulsion (minutes required).



Demulsibility Restoration

- Address poor demulsibility.
  - Ensure ST performance and reliability.

- Two main strategies for demulsibility restoration:

  1. Restoration by addition:
     - Top-up with new oil.
     - Top-up with aftermarket additives.

  2. Restoration by removal:
     - Ion exchange-based oil treatment.

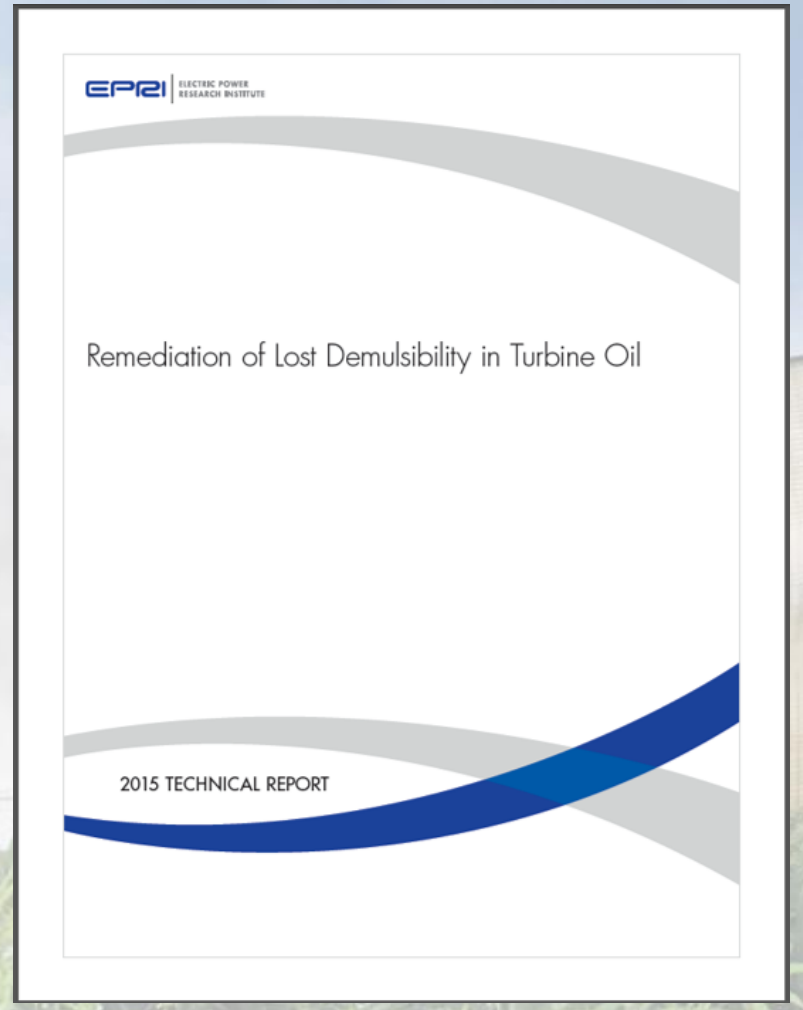
Restoration by Addition: New Oil Top Up

- 2015 EPRI paper:

- 3 Case studies:
  - Addition of GI makeup oil to GII reservoir improved demulsibility.

- Lab studies:
  - Not all GI oils improved demulsibility.
  - Case study improvements related to additives not base oils.

- Sweetening with foreign oil is risky.
  - Addition complicates oil chemistry.
    - Outcomes difficult to predict.
  - *"Oil suppliers recommend against these mixtures due to the unpredictable nature of oil interactions."*



Restoration by Addition: Additives

- 2014 Turbomachinery International article:
  - Studied aftermarket additive impact on oil demulsibility.

- Authors claim:
  - Additive improves oil solubility which *"may correct"* demulsibility.

- Claims not supported by evidence.
  - 18 in-service oils tested.
    - Demulsibility improved: 6
    - Demulsibility unchanged: 9
    - Demulsibility worsened: 3
    - On average, separation time increased!

- Addition complicates oil chemistry.
  - Outcomes more difficult to predict.
  - Risky strategy for critical assets.

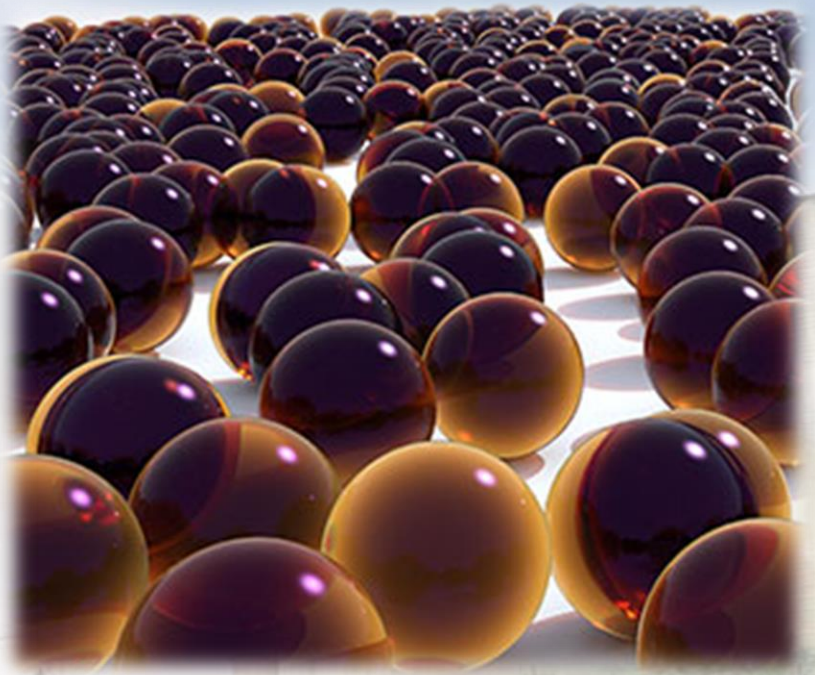
Turbomachinery International, 2014

Restoration by Removal: Ion Exchange

- Why complicate matters when you can make them more simple?
  - Addition ignores root cause.

- Engineered ion exchange (IX) resins:
  - Selectively remove polar contaminants from oils.
    - Acids, varnish, metals etc.
    - These contaminants stabilize emulsions.
  - Used in turbine applications for years.

- Simplify oil chemistry.
  - Restore in-service oil to a “like-new” state.
  - IX-treated oils separate from water like new oils.



Restoration by Removal: Ion Exchange

- Lab-scale ion exchange treatment of 14 different in-service steam turbine oils:

In-Service Oil Sample	Initial Demulsibility	Post IX Demulsibility	Emulsion Decrease (%)	Separation Time Improvement (%)
1	40-25-15 (>30)	40-40-0 (10)	100	67
2	39-8-33 (>30)	40-36-4 (>30)	88	0
3	5-0-75 (>30)	40-36-4 (>30)	95	0
4	40-33-7 (>30)	40-40-0 (10)	100	67
5	5-24-51 (>30)	46-34-0 (>30)	100	0
6	15-25-40 (>30)	41-38-1 (15)	98	50
7	40-37-3 (30)	40-38-2 (10)	33	67
8	0-27-53 (>30)	41-37-2 (25)	96	17
9	0-11-69 (>30)	9-22-49 (>30)	29	0
10	40-38-2 (15)	41-39-0 (10)	100	33
11	4-3-73 (>30)	37-37-6 (>30)	92	0
12	40-38-2 (15)	40-38-2 (10)	0	33
13	40-38-2 (10)	40-38-2 (5)	0	50
14	30-18-32 (>30)	40-40-0 (10)	100	67
Average	**24-23-33 (26)**	**38-37-5 (18)**	**85**	**31**

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Restoration by Removal: Ion Exchange

- Averages:

In-Service Oil Sample	Initial Demulsibility	Post IX Demulsibility	Emulsion Decrease (%)	Separation Time Improvement (%)
Average	24-23-33 (26)	38-37-5 (18)	85	31

- Treated oils 85% less-prone to emulsion formation:
- Treated oils separate from water 31% faster.
- Omit worst sample: average post IX demulsibility = 40-38-2 (17).
- Water separability of all 14 oil samples (100%) improved following IX.
  - *cf*. mixed results of GI or additive top-up.
- Polar contaminant removal restores demulsibility and provides additional benefits:
  - 43% ↓ in oxidation product levels.
  - 48% ↓ in acid number.
  - 64% ↓ in MPC varnish potential.

Restoration by Removal: Ion Exchange

CASE STUDY:

- On-site demulsibility restoration:
  - 759 MW coal-fired power plant.
  - ST oil with failing demulsibility.
- Oil Conditioning system with ICB™ installed.
- No makeup oil or aftermarket additives added.
- RESULTS:
  - 94% ↓ in emulsion forming tendency.
  - Water separated > 20 minutes faster.
  - AN, MPC and oxidation levels ↓.
- CONCLUSION:
  - Lab-scale results are scalable.
  - ICB™ restored demulsibility.

Sample	Demulsibility	Acid Number (mg KOH/g)	MPC ΔE	FTIR Oxidation (%)
Pre-ICB™	32-16-32 (>30)	0.08	5.5	45
Post-ICB™	39-39-2 (10)	0.06	3.9	28

Summary

- A layer of ST oil < 0.1 mm thick keeps up to 80% of the world's lights on.
  - ST oils frequently become contaminated with water.
    - Impairs lubrication abilities, promotes corrosion, wear and oil breakdown.

- Contaminant water takes 3 forms:
  - Dissolved: low levels can be accommodated by oil.
    - Relatively benign.
  - Free: "oil and water don't mix."
    - Harmful but easily kept away from critical components.
  - Emulsified: finely suspended within oil.
    - Harmful and cannot be easily separated.

- Strategies to restore demulsibility: complicate or simplify oil chemistry?
  - Foreign oil top-up/aftermarket additives: high risk and mixed results.
  - Ion exchange: low risk and consistent results.

- Ion exchange:
  - Decreases propensity towards emulsion formation.
  - Decreases oil-water separation time.
  - Removes harmful contaminants (acids, metals, varnish etc.).

"Oil and water should not mix. Fortunately, when they do, ion exchange provides ST operators with the tools required to keep their units running in optimal condition."


Thank you!
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