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Optimizing Next Generation Multi-Metal Wire Drawing Lubes

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Introduction to Advancion

(Formerly ANGUS Chemical Company)

- **Solutions-driven** manufacturer of **multifunctional additives**, intermediates and solvents for a broad range of applications and markets
- **Extensive track record of industry innovation** and technical applications development
- **Dual-source manufacturing** for major product lines to ensure global supply security
- 6 Regional **Customer Application Centers** to address local customer needs
- Strong focus on **Responsible Care®** and product stewardship to support the emerging trends of tomorrow

Innovations in Wire Drawing Fluids Improve Efficiency of Mobility

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Optimizing Next Generation Multi-Metal Wire Drawing Fluid Development Strategy

Need		
High Performing Multi-Metal Wire Drawing Fluid	Maximize Formulation pH Stability and Fluid Life	Cost-Effective Fluid to Make High-Quality Wires

Approach		
Semi-synthetic Fluid Provides Multi-Metal Compatibility	Amine Blends to Reduce Hydrolysis and Maintain pH	Additional Additives to Maintain Lubricant Properties and Improve Fluid Life

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Optimizing Next Generation Multi-Metal Wire Drawing Fluid Development Strategy

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Wire Drawing Requires High-Quality Fluids to Meet Increasing Demand

Copper Rod Break-Down

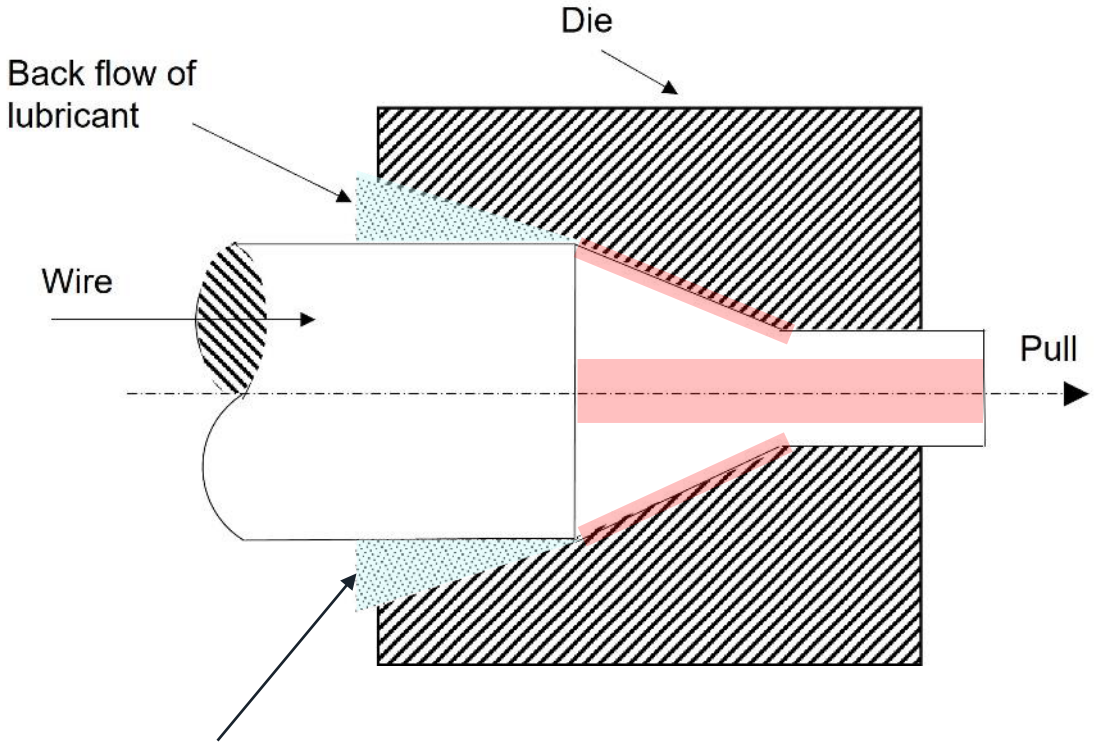
Copper Multiwire Drawing

Aluminum Rod Break-Down

Aluminum Wire Drawing

Advances in Semi-Synthetic Wire Drawing Fluids Increase Efficiency in Copper and Aluminum Wire Drawing

- Growing demand for electric power generation, storage, and utilization are driving market growth
- Semi-synthetic WDFs are frequently used for copper wire drawing
- Neat oils are traditionally used for aluminum wire drawing, but new soluble oil WDFs show advantages
- Developing new semi-synthetic WDFs using esters and amines offer performance and environmental benefits



Lubricant flow in wet wire drawing at high speeds

Lubricity Additive - Ester and Amine

Ingredients	Percent (%)
Mineral oil	50
Sodium Sulfonate	17
Emulsifier package	10
TMPTO Ester	**15**
Amine	**3**
Carboxylic Acid	0 - 2
Benzotriazole	0.3
Water	QSP
BIT 20%	1
Antifoam	0.05

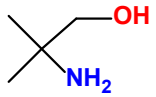
Semi-Synthetic Multi-Metal Formula

Provides multi-metal lubricant performance to increase efficiency of aluminum and copper wire drawing processes

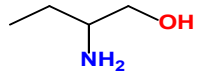
Amino Alcohols With Diverse Composition and Structures Offer Multifunctionality

- 1° amino alcohols with varying alkyl groups
- Containing one or two alcohol groups
- Effective pH stabilizer
- Range from highly water soluble to water miscible
- Excellent multi-metal compatibility
- Improves lubricity
- Extends fluid life
- Enables formulation optimization

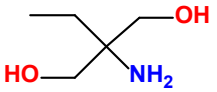
AMP
2-Amino-2-methyl propanol



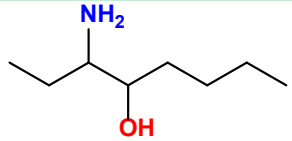
AB
2-Amino-1-Butanol



AEPD
2-Amino-2-ethyl-1,3-propanediol

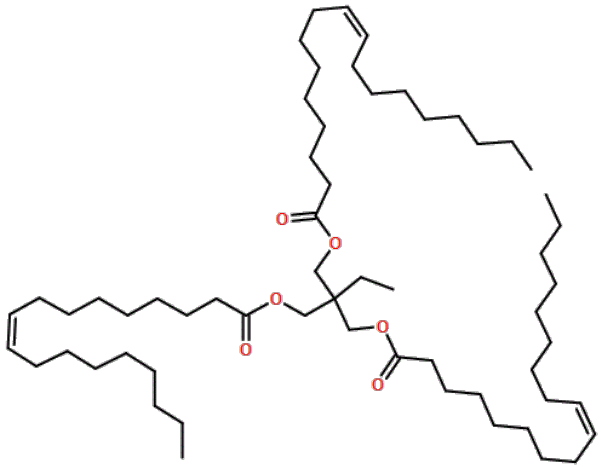


3A4O
3-Amino-4-Octanol



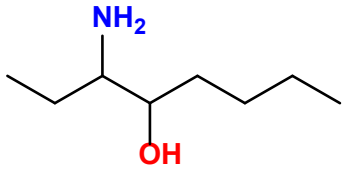
Lubricant Additive Structures Investigated

Ester

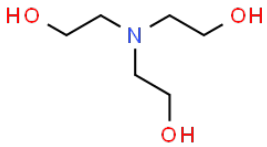


TMPTO
(Trimethylolpropane trioleate)

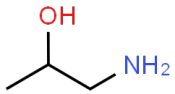
Amines



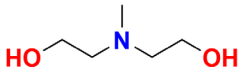
3A4O
(3-Amino-4-Octanol)



TEA
(Triethanolamine)

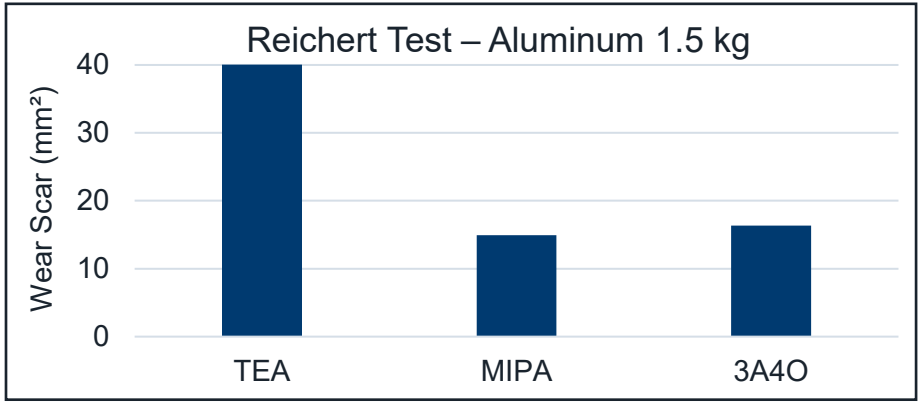


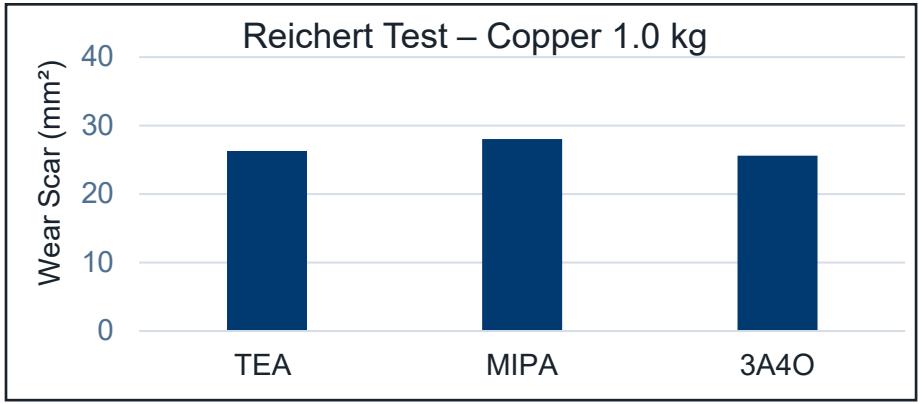
MIPA
(Monoisopropanolamine)



MDEA
(Methyl-diethanolamine)

Lubrication Power





Excellent Lubrication Obtained

- Semi-synthetic formulations show strong multi-metal lubrication properties
- 3A4O and MIPA show excellent lubrication on aluminum
- All have excellent lubrication on copper

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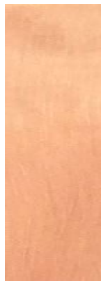
Multi-metal Compatibility

Alloys	TEA	MIPA	3A4O
pH	8.8	9.5	9.5
Aluminum			
Copper			

3A4O Shows Excellent Multi-Metal Compatibility

- 3A4O has the best performance on aluminum
- MIPA has the worst staining followed by TEA
- All have low copper staining

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3A4O Shows Excellent Emulsion Stability with Copper Powder

	TEA	MIPA	3A4O
Initial Aspect			
After 3 weeks			

Emulsion Stability with Copper Powder

- 3A4O and TEA show stability
- MIPA shows instability

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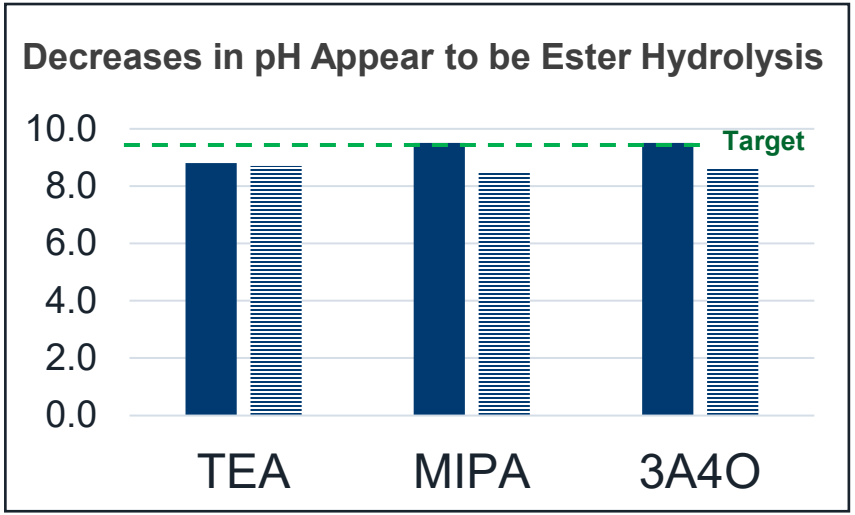
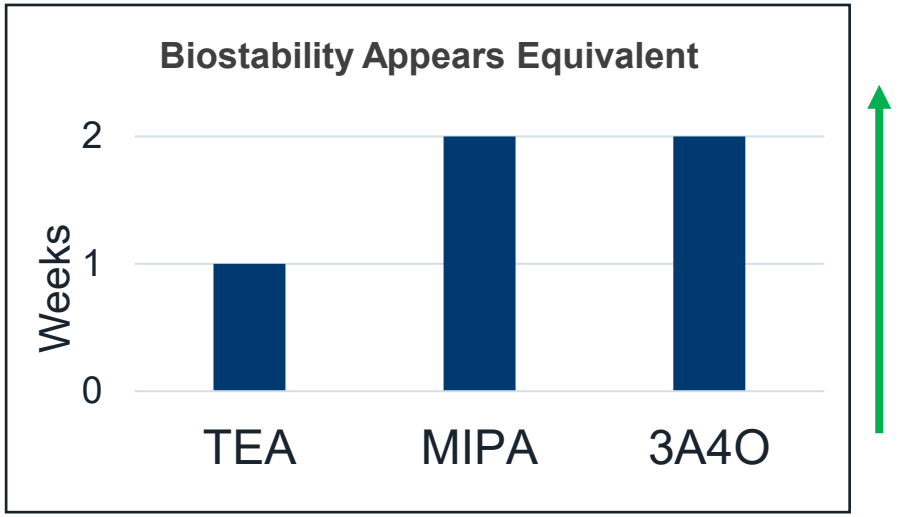
pH Change and Biostability Results Do Not Show a Direct Correlation



- TMPTO with TEA does not reach target pH
- TMPTO with 3A4O and MIPA shows a pH drop
- The pH drop is more prevalent at higher pH and can be attributed to hydrolysis of ester



- All formulations show similar microbial growth in bio-resistance challenge test

Semi-Synthetic Formulations Show Promise in Multi-metal Wire Drawing

- 3A4O formulation is stable and shows strong lubricity and compatibility with copper and aluminum
- Semisynthetic wire drawing fluids formulated with ester and amine show desired performance for multi-metal wire drawing
- 3A4O offered excellent aluminum and copper lubricity and corrosion control, and emulsion stability
- TEA offered good copper lubricity but did not have good aluminum lubricity
- MIPA showed formulation instability
- Biostability is an area to improve, and it is most likely due to ester hydrolysis

Chemical and Physical Properties of Ester Impact Hydrolysis

Attribute	TMPTO (C18)	TMP Ester (C8-C10)	Polymer Ester
Structure	TMP ester hindered unsaturated C18	TMP ester hindered saturated C8-10	Complex ester hindered and branched
Acid value	2.0	0.0	0.2
Water	0.1	0.0	0.0
KV @ 40C	46 cSt	20 cSt	340 cSt
Molecular weight	981.6	580.4	2000

- Lower acid value esters to improve hydrolytic, pH, and biostability

Higher Purity Esters Improve Hydrolytic Stability

Impact of Ester Properties

Ester Tested

- Polymer Ester
- C8-C10 TMP Ester

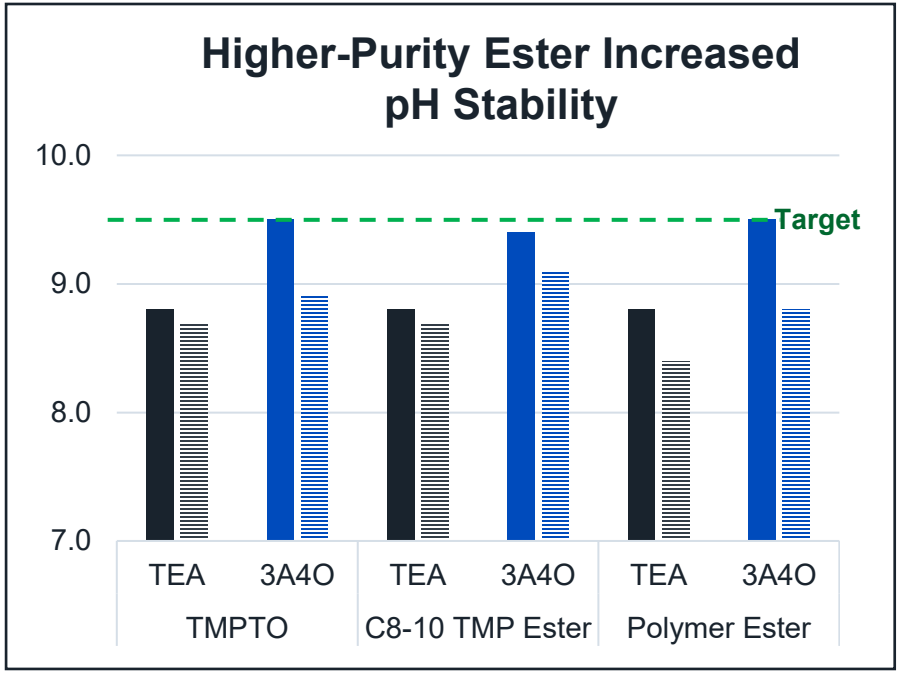
Amines Tested

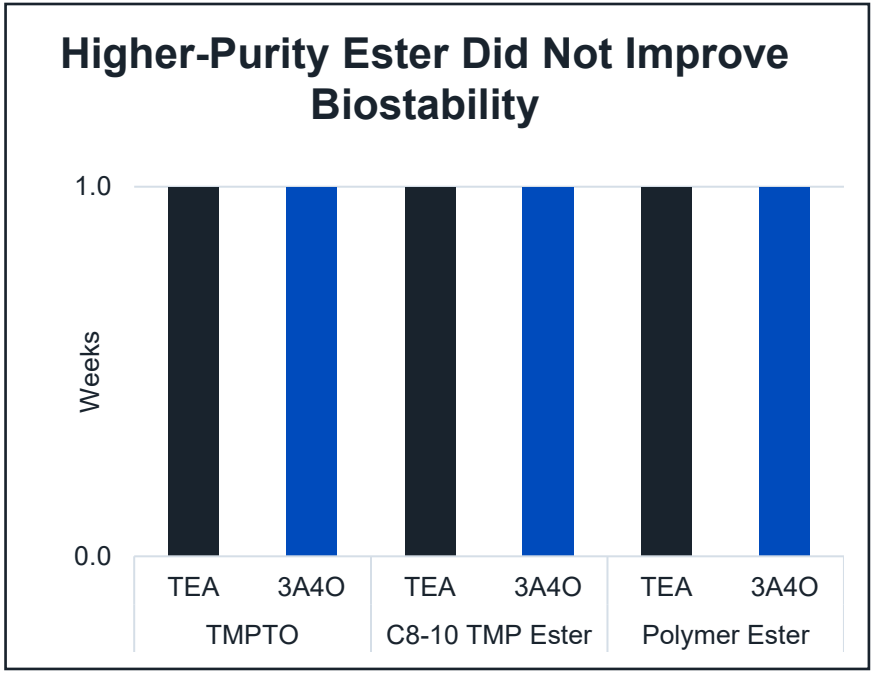
- TEA
- 3A4O

Target pH of 9.5

Ingredients	Percent (%)
Mineral oil	50
Sodium sulfonate	17
Emulsifier package	10
Esters	**10 - 15**
Amine	3
Carboxylic acid	0 - 2
Benzotriazole	0.3
Water	QSP
BIT 20%	1
Antifoam	0.05

Higher-Purity Ester Improved pH Stability but Did Not Increase Biostability





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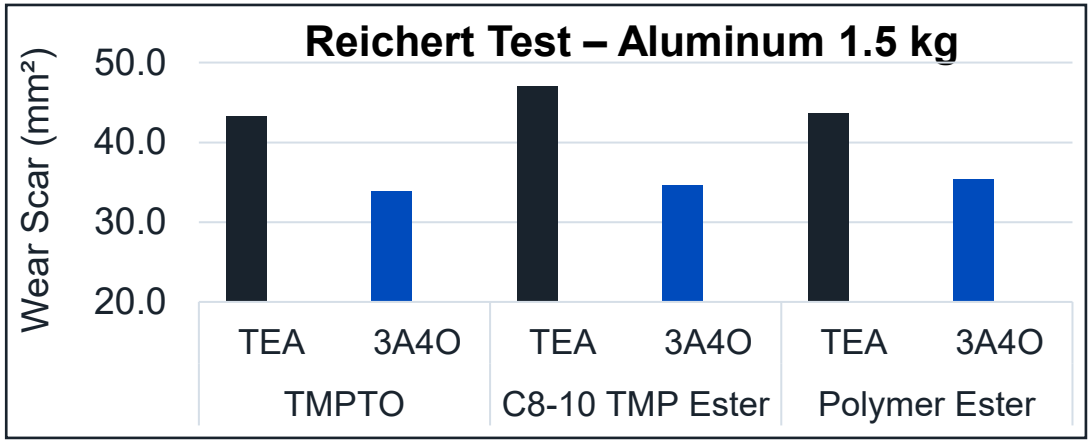
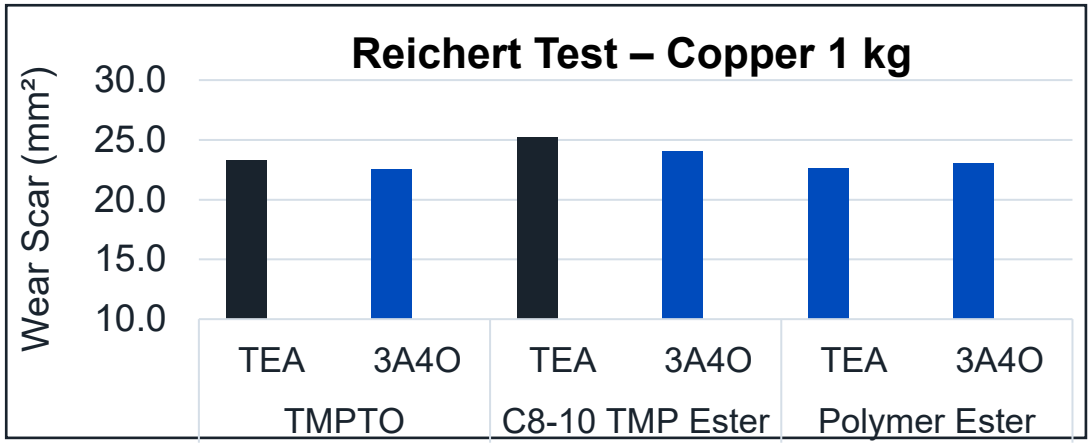
3A4O Shows Excellent Multi-metal Lubrication

- All esters show similar lubricity
- 3A4O has better Al lubricity than TEA
- Both have Cu lubricity
- 3A4O has excellent overall multi-metal lubricity





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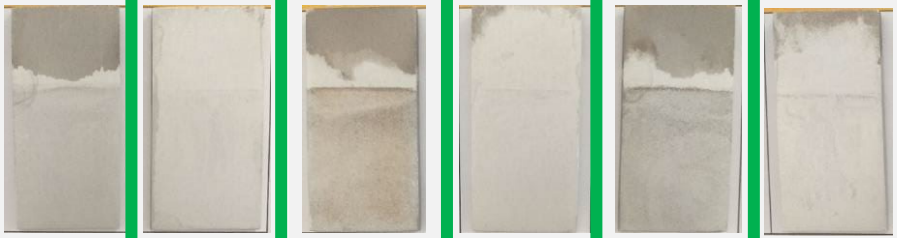
	TMPTO		C8-C10 TMP Ester		Polymer Ester	
Alloys	**TEA**	**3A4O**	**TEA**	**3A4O**	**TEA**	**3A4O**
pH	**8.8**	**9.5**	**8.8**	**9.4**	**8.8**	**9.5**
Aluminum						
Copper						

3A4O Shows Excellent Multi-Metal Compatibility

- Esters show similar multi-metal compatibility
- 3A4O offers better protection than TEA on aluminum
- 3A4O and TEA show good compatibility on copper

High-Purity Esters Improve pH Stability But Do Not Improve Biostability

Ester Quality

- Higher-purity TMP ester improved pH stability
- No impact observed on biostability

Ester Structure

- High purity TMP ester showed better hydrolytic stability than polymer ester
- TMP and polymer esters show good lubrication, corrosion control and formulation stability
- No impact observed on biostability

Amine and Ester Properties

- 3A4O showed excellent multi-metal performance
- TEA did not have good aluminum compatibility
- 3A4O and TEA formulations had good pH stability with higher-quality esters
- Biostability still not meeting expectations

Optimizing Next Generation Multi-Metal Wire Drawing Fluid Development Strategy

Need

High Performing Multi-Metal Wire Drawing Fluid	Maximize Formulation pH Stability and Fluid Life	Cost-Effective Fluid to Make High-Quality Wires

Approach

Semi-synthetic Fluid Provides Multi-Metal Compatibility	Amine Blends to Reduce Hydrolysis and Maintain pH	Additional Additives to Maintain Lubricant Properties and Improve Fluid Life

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Amine Blends Scavenge Acid of Low Purity Ester

ESTER TESTED

- TMPTO

AMINES TESTED

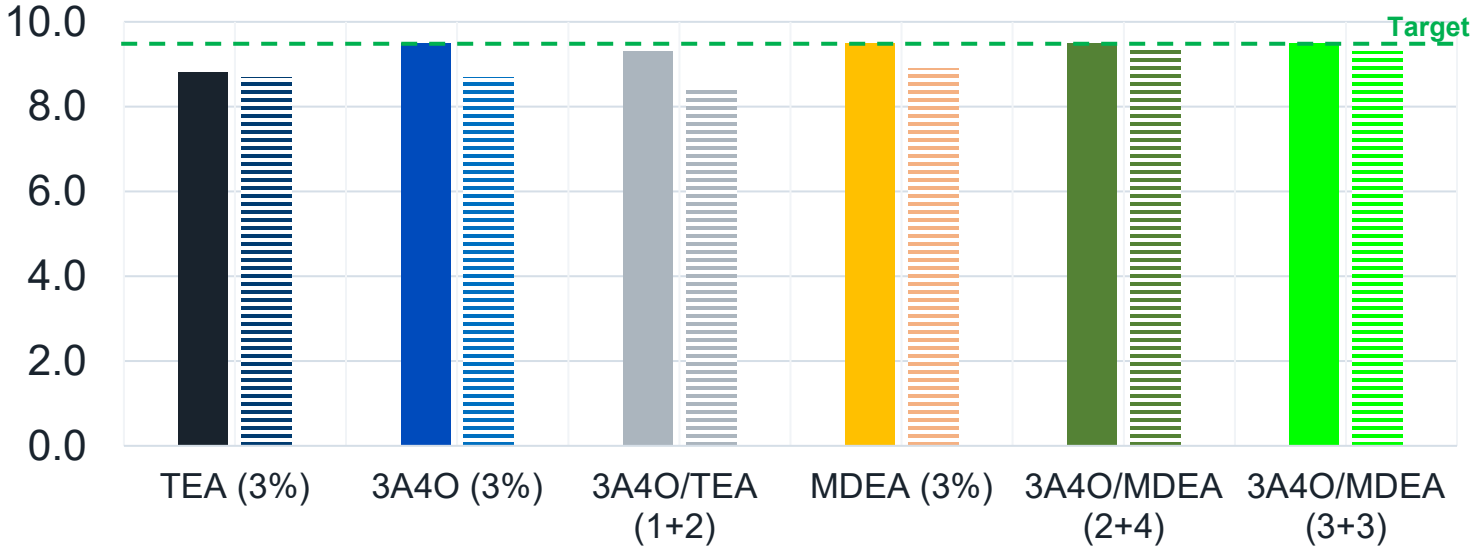
- 3A4O
- TEA
- MDEA

TARGET PH OF 9.5

Formulation with Amine Blends to Improve Fluid Life of Low Purity Ester

Ingredients	Weight %
Mineral oil	50
Sodium Sulfonate	17
Emulsifier package	4 - 6
TMPTO Ester	15
Amine(s)	**3 - 6**
Carboxylic Acid	0 - 3
Benzotriazole	0.3
Water	QSP
BIT 20%	1
Anti oxidant	0.4
Antifoam	0.05

3A4O Blended With MDEA Improved pH Stability of Low-Purity TMPTO Ester



- Highest pH stability is obtained at target pH with blends 3A4O and MDEA
- Blending 3A4O and TEA did not show desired pH stability
- Blends of 3A4O showed desired pH stability and can be further optimized

3A4O Blended with MDEA Increased Biostability

ESTER TESTED

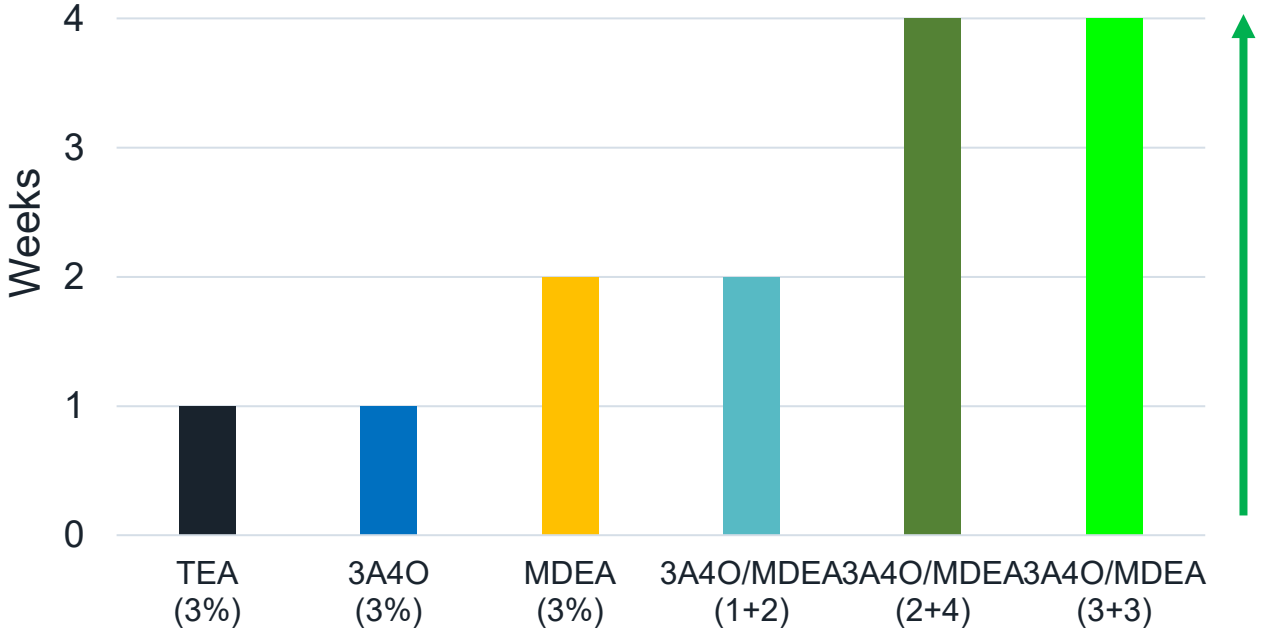
- TMPTO

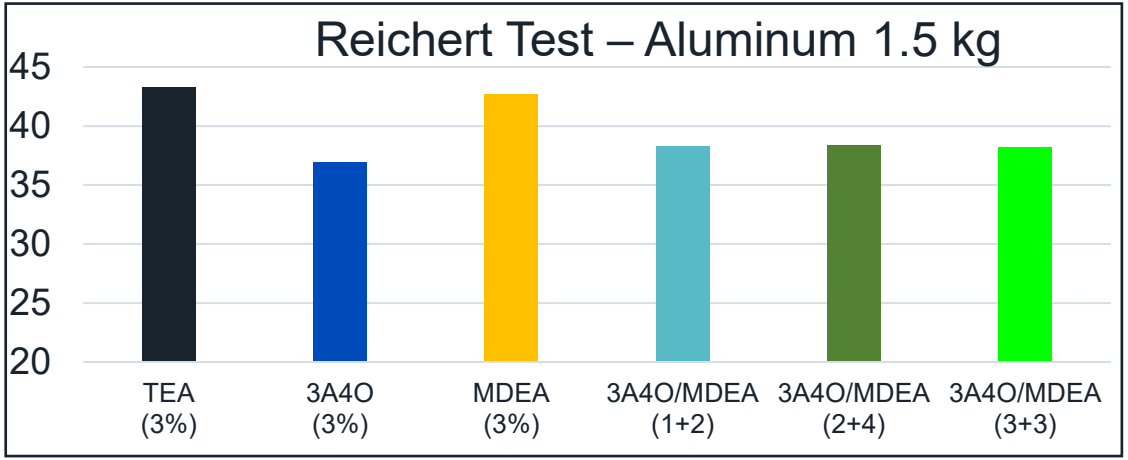
AMINES TESTED

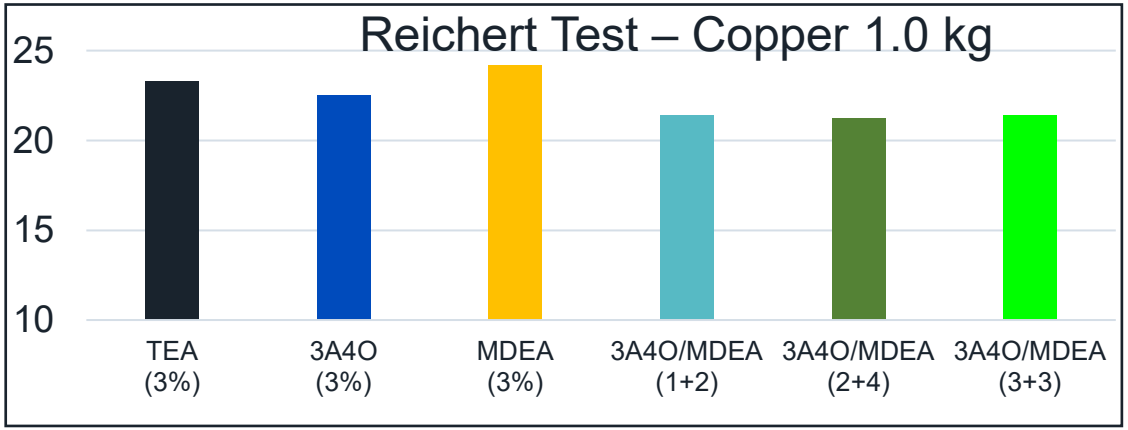
- 3A4O
- TEA
- MDEA

TARGET PH OF 9.5

3A4O Blended With MDEA Significantly Increased Fluid Life







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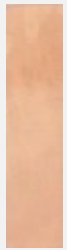
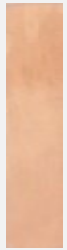
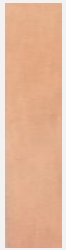
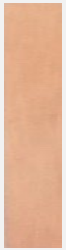
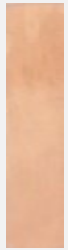
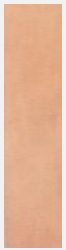
3A4O Blended with MDEA Shows Multi-Metal Lubrication Power

Results

- 3A4O (alone or in blends) shows better lubrication than MDEA or TEA on aluminum
- All formulations show good lubrication on copper

3A4O Blended with MDEA Maintains Multi-Metal Compatibility

- 3A4O offers the best aluminum compatibility, followed by blends of 3A4O with MDEA
- All formulations show good copper compatibility

Alloys	TEA (3%)	3A4O (3%)	MDEA (3%)	3A4O/MDEA (1 + 2)	3A4O/MDEA (2 + 4)	3A4O/MDEA (3 + 3)
pH	8.8	9.5	9.5	9.5	9.4	9.4
Aluminum						
Copper						

3A4O Blended with MDEA Improved Fluid Life of Low-Purity TMPTO Ester

- 3A4O blended with MDEA improved pH stability of low-purity TMPTO ester and increased biostability
- 3A4O blended with TEA did not reach target pH and did not improve pH stability of low-purity TMPTO ester
- 3A4O alone and blended with MDEA showed excellent multi-metal lubricant performance

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High Performing Multi-Metal Wire Drawing Fluid	Maximize Formulation pH Stability and Fluid Life	Cost-Effective Fluid to Make High-Quality Wires

Approach

Semi-synthetic Fluid Provides Multi-Metal Compatibility	Amine Blends to Reduce Hydrolysis and Maintain pH	Additional Additives to Maintain Lubricant Properties and Improve Fluid Life

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Addition of an Anti Oxidant Additive to Improve Fluid Life

Ester tested

- TMPTO

Amines tested

- 3A4O
- TEA
- MDEA

Anti Oxidant Additive tested

- Mixture of octylated and butylated diphenylamine

Target pH of 9.5

Ingredients	Weight %
Mineral oil	50
Sodium Sulfonate	17
Emulsifier package	4 - 6
TMPTO Ester	15
Amine(s)	3 - 6
Carboxylic Acid	0 - 3
Benzotriazole	0.3
Water	QSP
BIT 20%	1
Antioxidant	**0.4**
Antifoam	0.05

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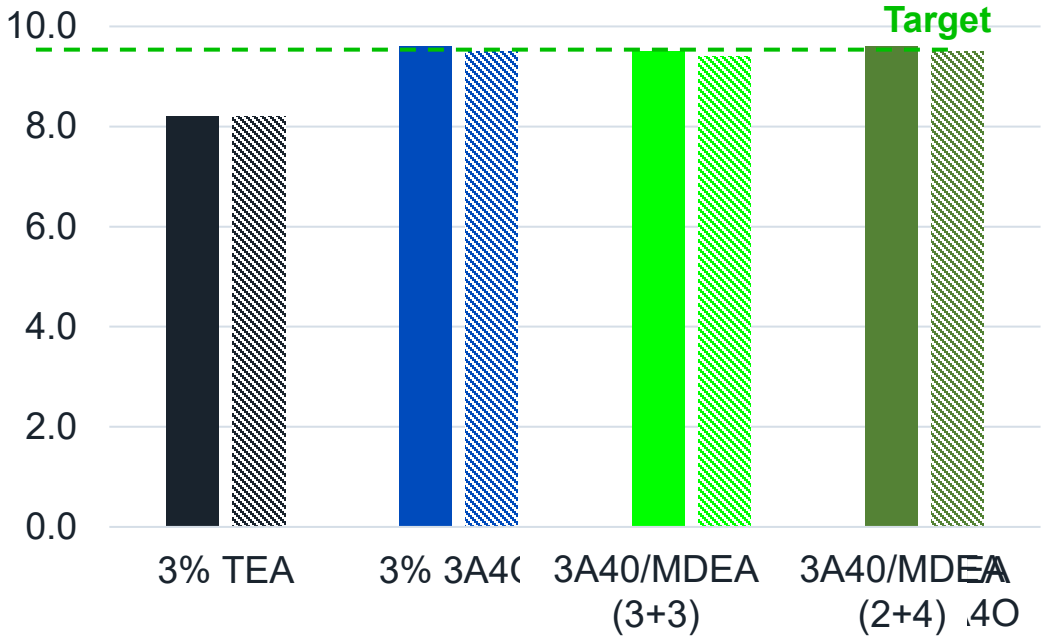
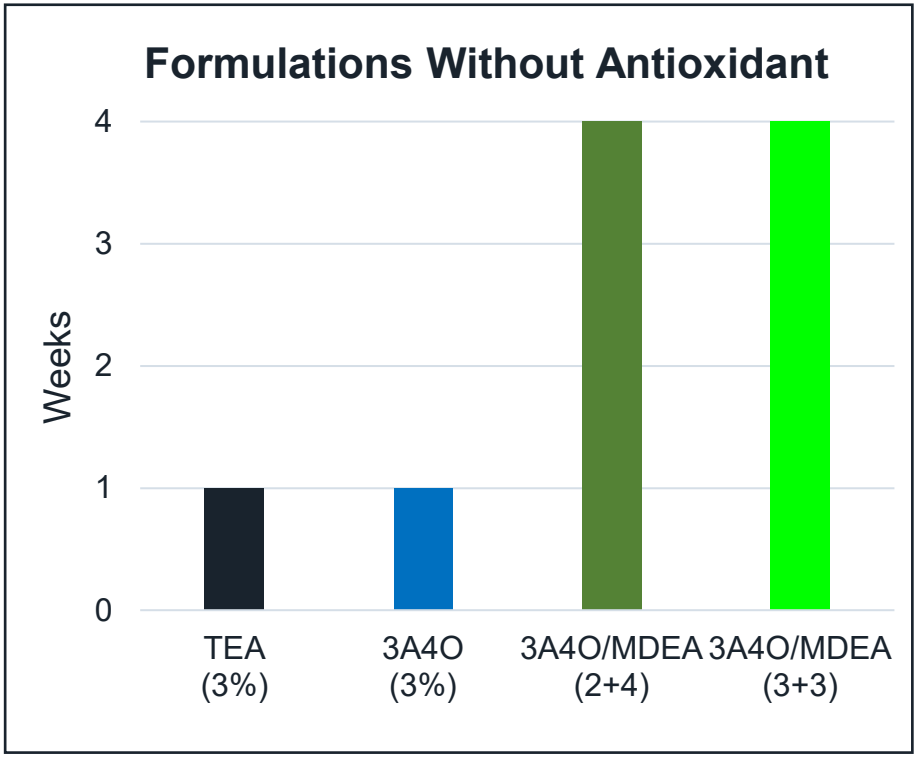
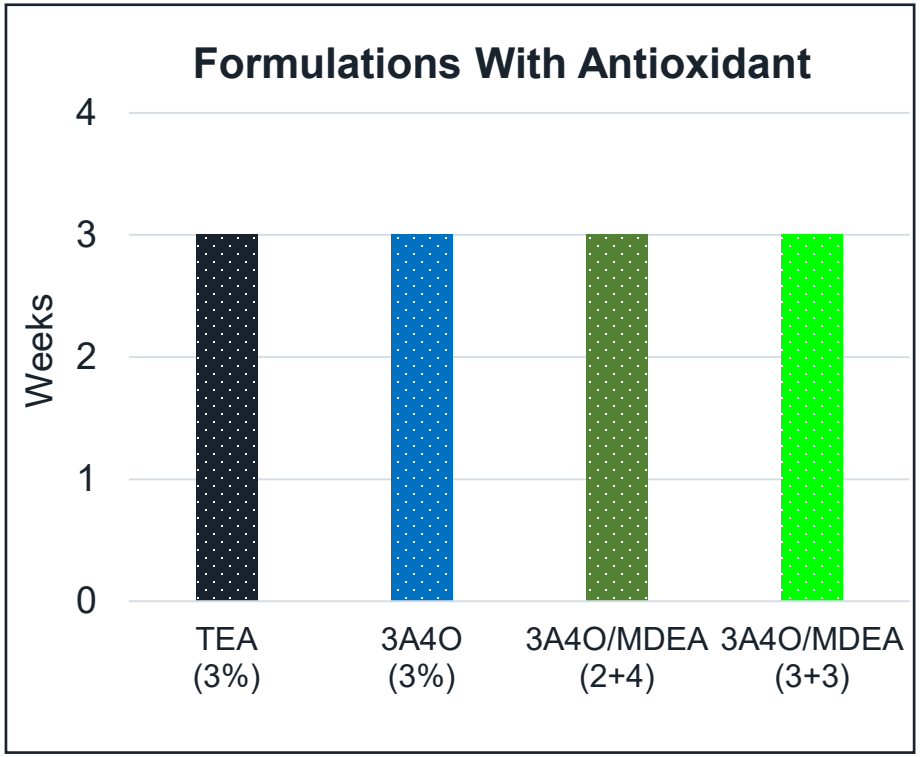
Antioxidant Additive Improved pH Stability

- 0.4% antioxidant was added to all TMPTO containing wire drawing fluid formulations
- All formulations showed very good pH to stability



All Formulations with Antioxidant Additive Showed Similar or Better Biostability Results





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Addition of a Phosphate Ester

Ester tested
- TMPTO

Amines tested
- 3A4O
- TEA
- MDEA

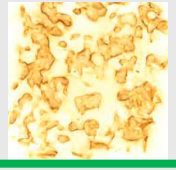
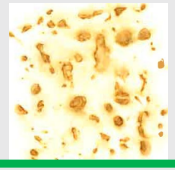
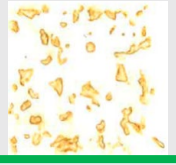
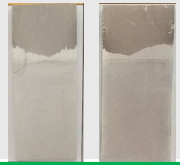
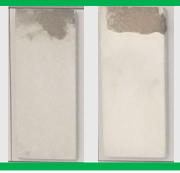
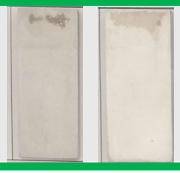
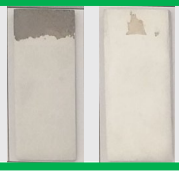
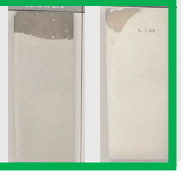
Phosphate Ester tested
- Phosphoric acid, mono- and di-C11-14 (linear and branched) alkyl esters

Anti Oxidant Additive tested
- Mixture of octylated and butylated diphenylamine

Target pH of 9.5

Ingredients	Weight %
Mineral oil	50
Sodium Sulfonate	17
Emulsifier package	4 - 6
TMPTO Ester	15
Amine(s)	3 - 6
Carboxylic Acid	0 - 3
Benzotriazole	0.3
Phosphate Ester	**2**
Water	QSP
BIT 20%	1
Antioxidant	0.4
Antifoam	0.05

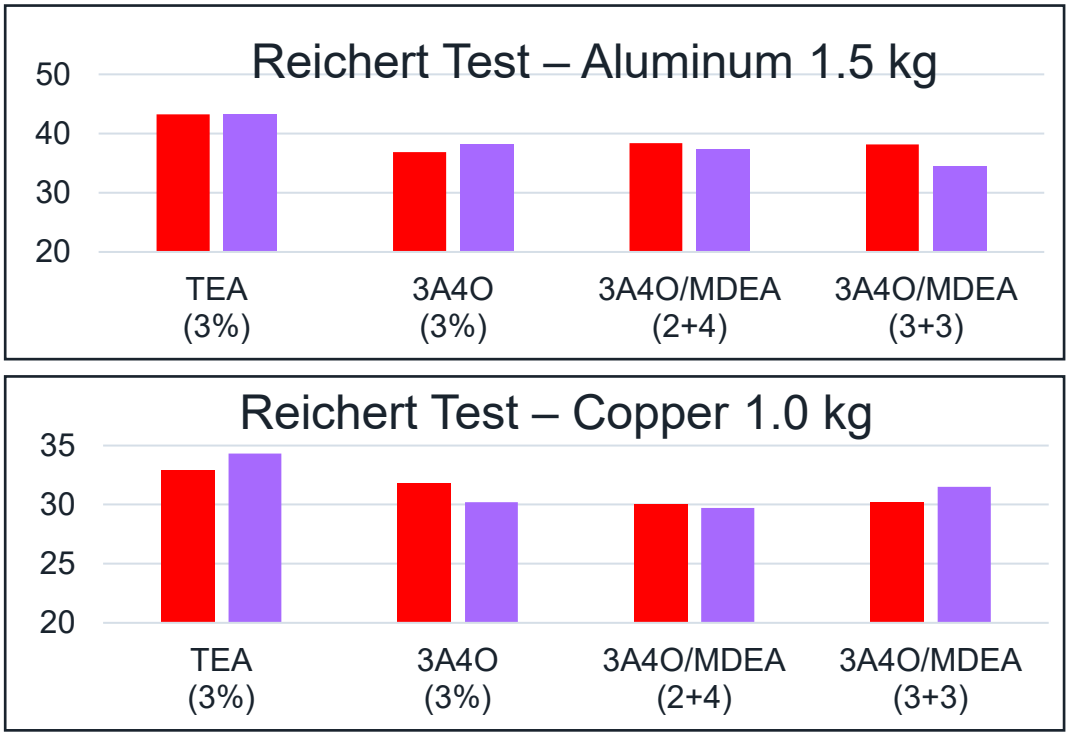
Multi-metal Protection

Dilution	TEA	3A4O	3A40/MDEA (3+3)	3A40/MDEA (2+4)
No Phosphate Ester				
2% Phosphate Ester				
No Phosphate Ester				
2% Phosphate Ester				

- 2% phosphate ester was added to all formulations
- All formulations with phosphate ester showed similar or improved ferrous and aluminum corrosion resistance

Advancion

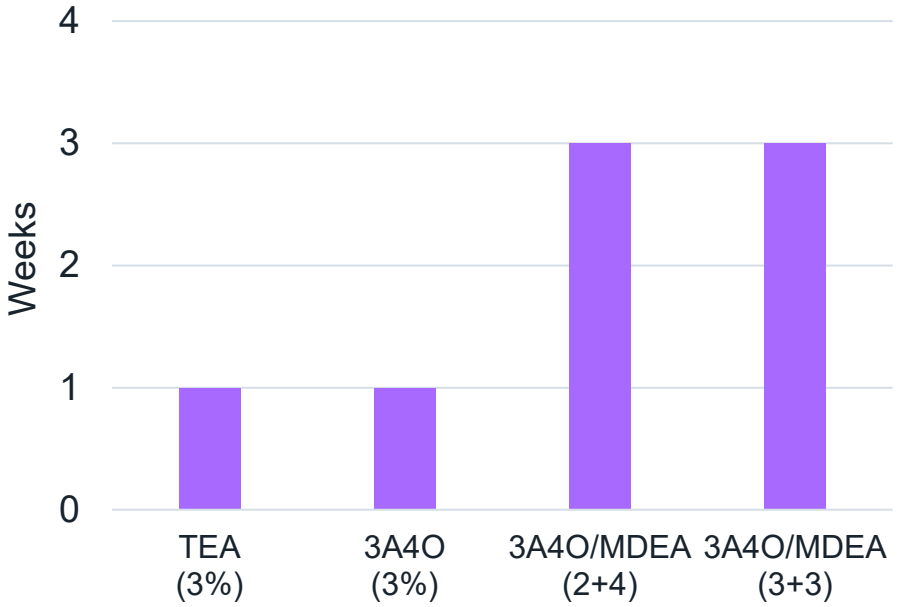
Lubrication Power with Addition of 2% of Phosphate Ester



- No significant impact on lubrication is obtained by adding a phosphate ester

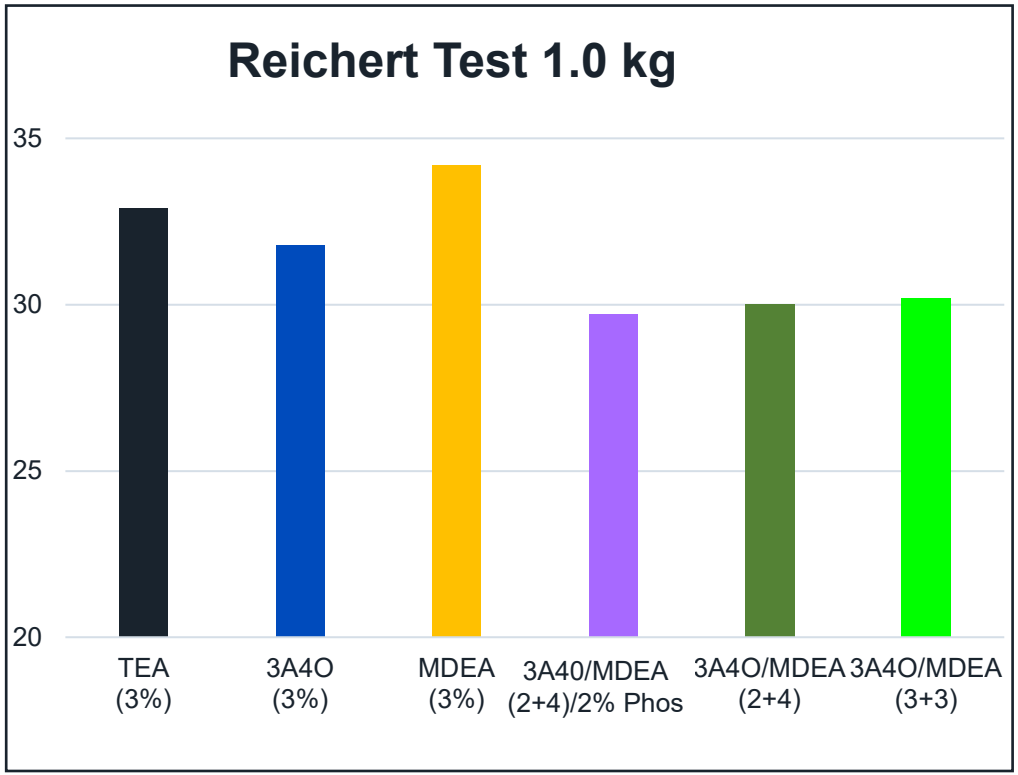
Advancion

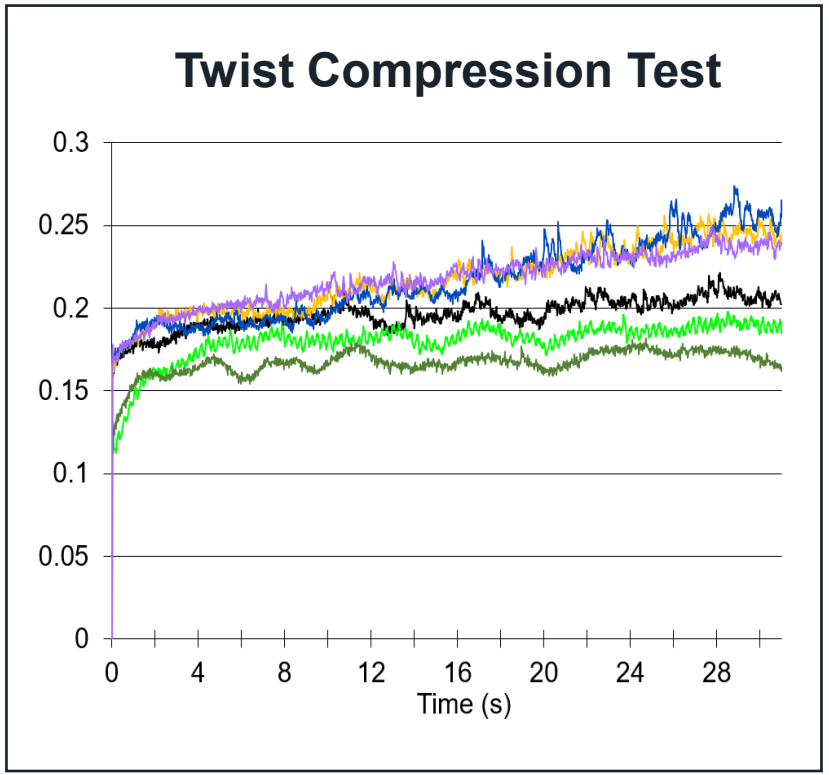
Biostability of Formulations with Addition of 2% Phosphate Ester



- 2% Phosphate Ester does not improve biostability
- It offsets the improvement gained in single amino alcohol formulations gained from the antioxidant
- 3A4O/MDEA blends continue to have higher biostability

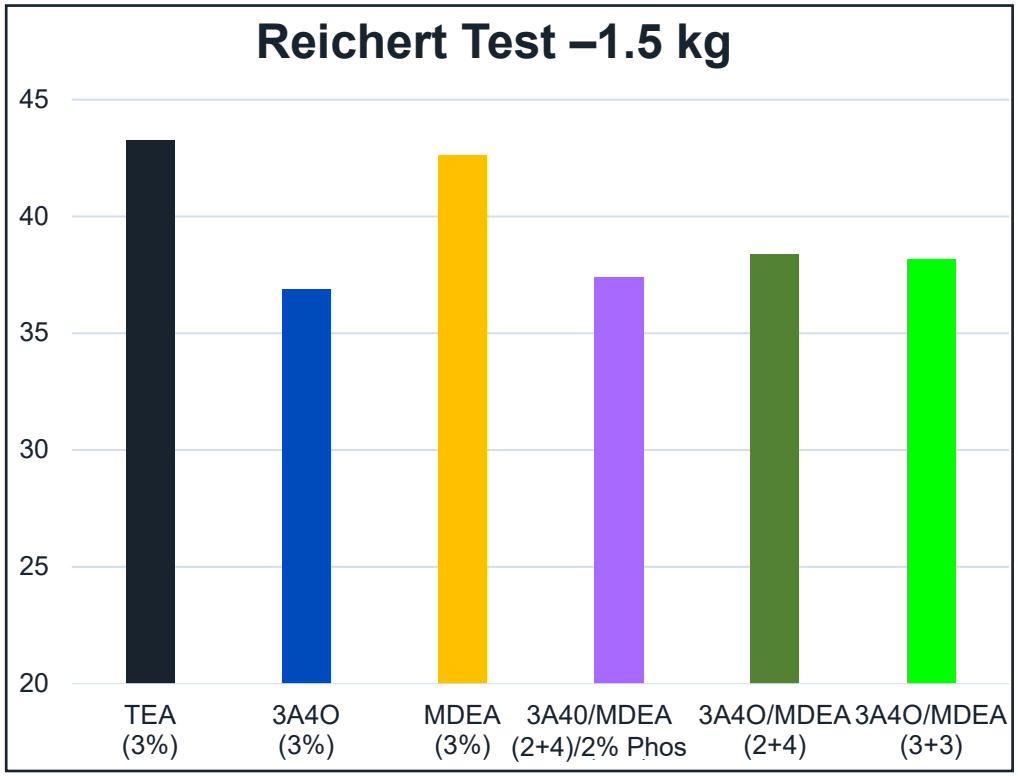
3A4O Blended with MDEA Shows Multi-Metal Lubrication Power on Copper

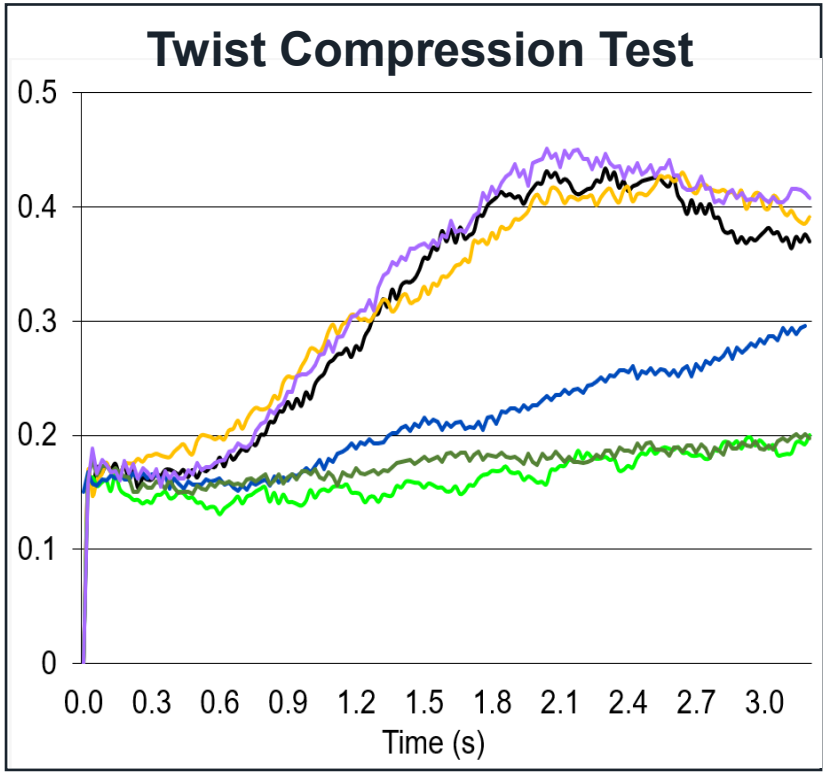




Advancion

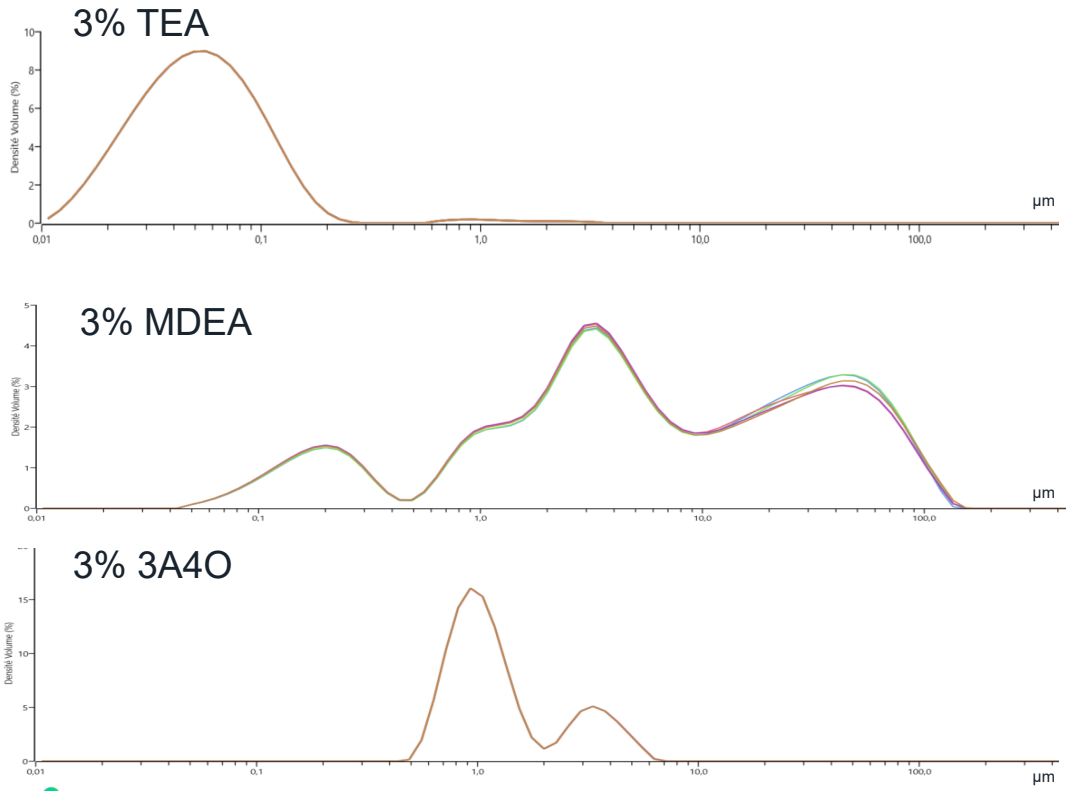
3A4O Blended with MDEA Shows Lubrication Power on Aluminum in Different Operating Regimes





Advancion

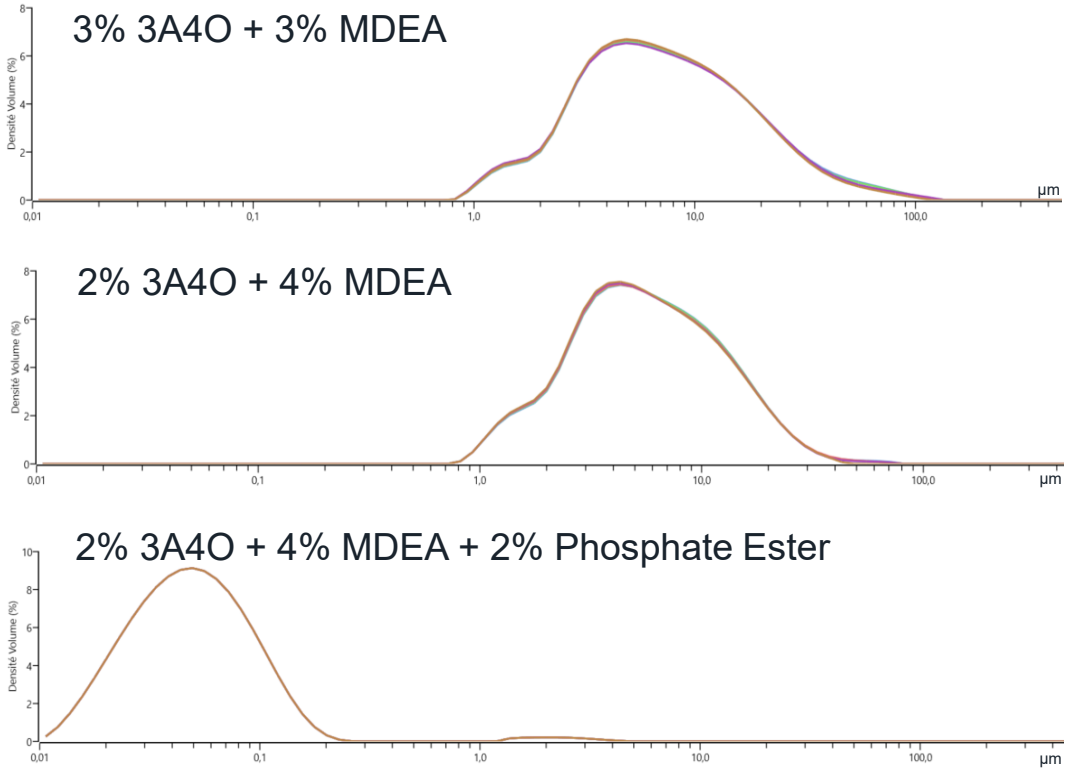
Emulsions Properties Impact Lubrication



Droplet Size Distribution

- TEA - gives the smallest droplet size and the distribution is large.
- MDEA - gives a multimodal droplet size and broad distribution.
- 3A4O - gives a larger droplet size compared to TEA and bimodal distribution. Larger droplet size can be beneficial for the lubricity.

Stable Emulsion with Larger Particle Size Provides Higher AI Lubrication



- 3A4O and MDEA blends - give large droplet size and broad distribution. This is beneficial for AI lubricity.
- 2% of phosphate ester in 3A4O/MDEA (2+4) gives a smaller droplet size and a distribution similar to TEA.

Antioxidant and Phosphate Ester Additives Provide Complimentary Benefits in Formulations to Amino Alcohols

Antioxidant Impact

- Antioxidant improved pH stability but not improve bioresistance in TMPTO formulations
- Antioxidant slightly reduce lubrication power

Phosphate Esters

- Provide a benefit on aluminum staining
- The impact on other parameters is negligible

Summary and Next Steps

- Semi-synthetic wire drawing fluids using esters, amines, and other additives demonstrate efficient wire drawing performance on Aluminum and Copper
- 3A4O (3-amino-4-octanol) showed strong WDF formulation versatility and benefits in multi-metal compatibility
- 3A4O mixed with multiple amino alcohols shows promise for wire drawing fluids and will be investigated further
- Performance can be further optimized through more research and collaboration with formulators

THANK YOU