Base Stocks: A Formulator’s Market Place

Yew Chin Law
Infineum Singapore Pte Ltd

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Presentation Outline

- Base stocks: basic definitions and API group classification
- Base stocks: manufacturing processes overview
- Basics of base stock chemistry
  - Example of relationship between chemistry and API definitions
- Industry drivers for better quality base stocks
- Technical data highlighting performance differences
  - API base stock performance improvements
  - AO / base stock effects
- Conclusions
The API Base Stock Classification is Practical

<table>
<thead>
<tr>
<th>Group</th>
<th>VI</th>
<th>Saturates</th>
<th>Sulfur</th>
<th>Other</th>
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<td>I</td>
<td>80-120</td>
<td>≤90%</td>
<td>≥0.03%</td>
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<td></td>
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<td>Typical 65-85</td>
<td>Typical 300-3000ppm</td>
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<td>II</td>
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<td>PAO / PIO</td>
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<td>Everything Else</td>
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<td>IV / VI</td>
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- The API base oil classification system segments base stocks based upon 3 chemical differences
- Base oil interchange guidelines developed as part of API classification permit “worse for better” base oil substitution in programme developments
Manufacturing Routes to Conventional Base Stocks

Distillation → VGO → Acid → Clay → Base → “Neutral” B/S

Remove aromatics and other impurities

Distillation → VGO → Solvent Extractor → Solvent Dewaxer → Hydrofinisher → “Solvent Neutral” B/S

Lower costs and better pour points
Manufacturing Routes to Group II and III Base Stocks

- Distillation → VGO → Hydrocracker → Hydro Dewaxer → Group II
- Wax → Hydrocracker → Catalytic Dewaxer → Hydrofinisher → Group II
- Group III

Greatly improved quality
Manufacturing Routes Affect Base Stock Composition

Different options exist to produce different quality base stocks

The most appropriate option depends on the producer:
- Crude source and flexibility
- Existing equipment

New catalysts and process combinations are making the production of better quality Group II and III base stocks easier

The base stock manufacturer prepares base stock to envelope target values of performance, as defined by the API classification, reinforced by internal specifications:
- Key driver is economics
- As a rule of thumb, increasing “conversion” reduces overall plant yield

The API classification system broadly describes different properties of different base stock groups
How does base stock chemistry link to performance aspects?
Base Stock Chemistry: Many Types of Molecular Species are Present

Paraffins

Aromatics

Mono-naphthenes

Poly-naphthenes

Group IV

Group III

Group I

Paraffin

Mono-naphthene

Poly-naphthene

Aromatic

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Base Stock Chemistry: Molecular Species Inter-Conversion
“In Theory” Viscosity Index by Chemistry

How does the picture of a base stock being a mixtures of molecules work with regards to a performance attribute?

Flexible molecules have high VI:
- Relates to changes in configuration with temperature
- Paraffins > Naphthenes > Aromatics

At low temperature

VI ~ -10
VI ~ 65
VI > 250

At low temperature
“In Practice” Viscometric Performance by VI

Data Trends Derived from Group III and Group IV Base Stocks

Higher VI = better low temperature performance for same “volatility”
In Summary: API Classification Describes Chemistry

API: base stock classifications

Base stock performance

Base stock chemistry

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In Summary: API Classification Describes Chemistry

What drives performance requirements?

API: base stock classifications

Base stock performance

Base stock chemistry

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“In Practice” Viscosity Performance by VI

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Base Stock Chemistry: Many Types of Molecular Species are Present

Paraffins
Mono-naphthenes
Aromatics
Poly-naphthenes

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Hardware Drivers – The “Virtuous Circle”

Better durability

Longer service intervals

Longer oil drains

Hardware specific Formulations

Grade proliferation

Change in base oils & additives e.g. lower P, S, ash (Low/Medium SAPS)

Life is getting tougher for the formulator!

Greater use of non-Conventional base stocks

New and more costly additive solutions

Reduced emissions

Better fuel economy

Better cleanliness

Higher costs
The Formulators’ Challenge

- Different base stock groups bring different chemistries:
  - MW distributions, aromatics, paraffins, etc.
  - True synthetic (Group IV) base stocks can sometimes provide (almost) single component chemical systems

- Formulators need to identify the right base stock combinations for the performance levels desired by customers at the lowest possible cost
  - Additive technologies (to protect the lubricating base oil)
  - Base stocks (for viscosity grade and performance targets)

- API classification system developed upon real data with understanding that engine performance is not so sensitive as to detect minor differences in chemistry

- By developing and enhancing our understanding of base stocks at a molecular level we will be able to optimise formulations for better cost and performance value
An Approach to Understanding Base Stock Differences

- Lubricating oils are formulated to a viscosity grade and performance targets

- Approach used here:
  - Bench test comparisons: 3 additive technologies were chosen, formulated to 2 viscosity grades
  - Relative Group I / II / III and IV base stock quantities varied to maintain viscometrics

- Introduction of different quantities of molecules to the test matrix

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HDD Technology #1 Shows Different Performance in Soot Control with Different Base Stock Chemistry

- Soot viscosity control bench test
  - Adpack response is improved with better quality base stock
Anti-Oxidants and Base Stocks Work Hand-in-Hand

- Base stock quality is important
- AO system is important

Different AO systems respond differently to base stock chemistries
- Some may not give such distinctive improvements in performance

General trend exists – does not always occur that a particular AO will work better in a better base stock group
Anti-Oxidant and Base Stock Effect is also Observed in Engine Test Performance

- Where data exists, performance differences based upon base stock type for identical additive package technology supports bench test data
- For the same AO technology, better engine test performance by base stock

![Graph showing Averaged Oxidation Control Performance for API Group II and API Group III](image-url)
Anti-Oxidant and Base Stock Effects are Consistent

- Where data exists, performance differences based upon base stock type for identical additive package technology supports bench test data
  - For the same AO technology, better engine test performance by base stock
  - AO technology gives improved bench test response in better base stock
  - Anti-Oxidants and base stocks are working hand-in-hand

- Change to better quality base stock should improve performance

- Effect shown is bench test improvement of AO; additive system response
Statistical Modelling Permits Observation of Base Stock Performance Trends by Engine Test

- Statistical modelling is used to observe engine test results trends (responses) against additive technology changes (factors).
- Addition of base stock terms to the models permits observation of base stock influence upon engine test performance.

Sequence IIIG: % Viscosity Increase

Group II

Group III
Statistical Modelling Permits Observation of Base Stock Performance Trends by Engine Test

- Statistical modelling is used to observe engine test results trends (responses) against additive technology changes (factors).
- Addition of base stock terms to the models permits observation of base stock influence upon engine test performance.

Sequence IIIG:
% Viscosity Increase

Base stock performance factors ($x, y', y''$)
Future Base Stock Technologies

Gas-To-Liquid technologies offer the opportunity to synthesise large quantities of Group III base stock from basic building blocks

- The Fischer-Tropsch process makes normal paraffins
- Hydrocracking / hydroisomerisation can then be used to obtain desired MW and isomerisation of products

With very high paraffins content, if all GTL projects come to fruition there will be a significant increase in the amount of high quality base stocks available to the lubes industry at potentially affordable prices

There is some uncertainty around this scenario:

- XOM planned GTL project has been put on hold in favour of natural gas projects in Qatar
- Pricing / plant production of GTL diesel / base stocks / waxes

There is still a general movement to better quality base stock systems

By understanding base stock chemical differences and their effects upon / in hand with additive systems, we can stay ahead in the understanding game
Summary

- API base stock classification system broadly describes base stock performance
  - Practical approach, underpinned by chemistry

- Different manufacturing routes and crude sources are used to prepare different base stocks

- Additives can suppress the properties imparted to a formulation by the base stocks in use but base stock quality is critical, especially at “top tier” oil formulation levels

- Formulators can adapt and change, trade base stock qualities and quantities within a formulation, to help achieve the desired performance attributes

- Additive formulation space is becoming more constrained
  - Better quality base stocks can be used to afford greater formulation space

- Improved understanding of base stock chemistry can help optimise formulations and bring value to customers