Enhancing Hybrid Engine Performance with VIIs:

Correlation between structure and performance of specialty elastomers for oil modification

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versalis

European Emission Reduction Policies and Their Impact on Sustainability

The European Union has implemented several directives aimed at reducing CO_2 emissions from vehicles, driving sustainability in the automotive sector.

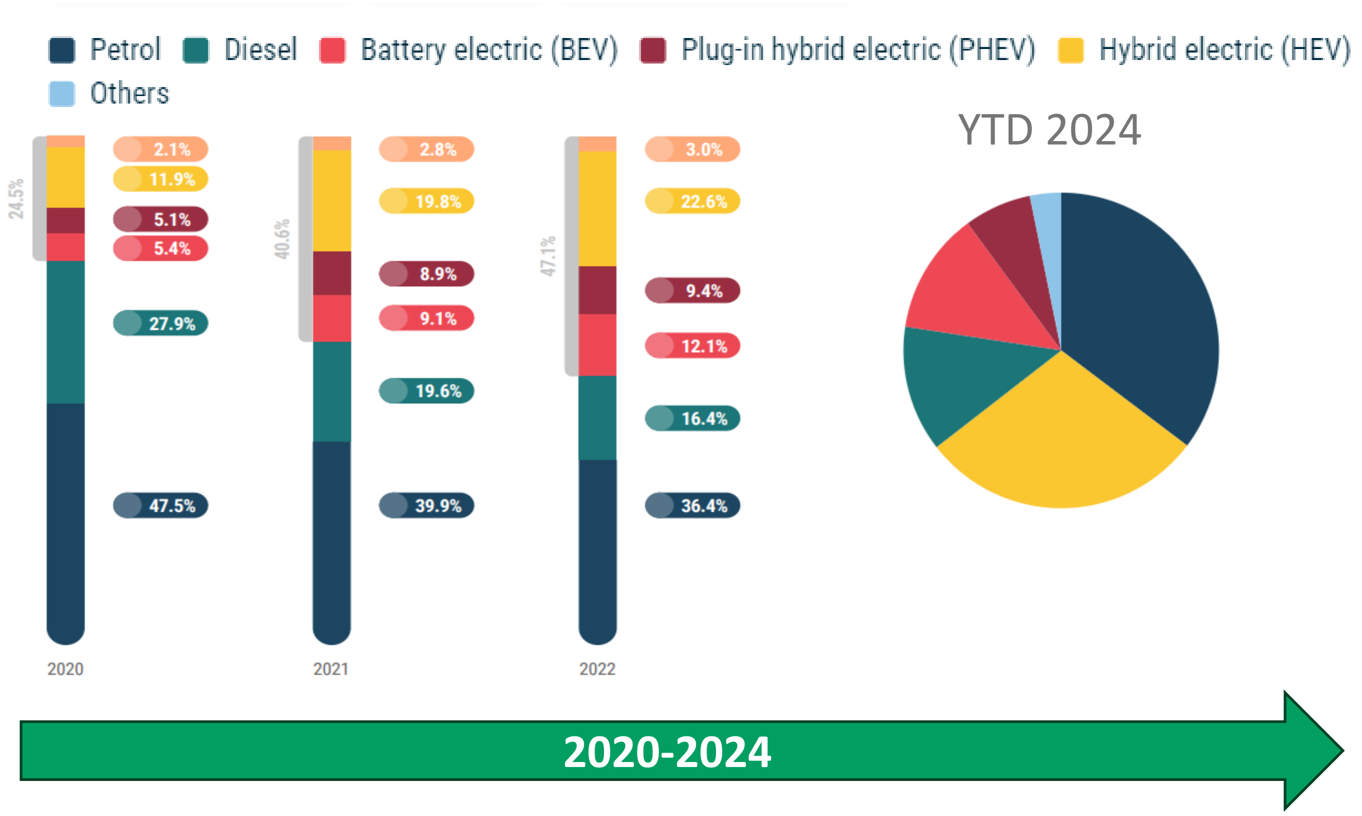
- **Key Directives**:
  - **EU Regulation 443/2009**: Sets mandatory emission reduction targets for new cars. The regulation requires that by 2015, the average CO_2 emissions from new cars should be no more than 130 grams per kilometer, and by 2021, this target is set to be reduced to 95 grams per kilometer.
  - **EU Regulation 2019/631**: Establishes CO_2 emission performance standards for new passenger cars and new light commercial vehicles. **It mandates a 15% reduction in CO_2 emissions by 2025 and a 37.5% reduction by 2030 for new cars compared to 2021 levels.**
- **Impact on Sustainability**:
  - The introduction of these regulations has significantly lowered the average CO_2 emissions from new vehicles, contributing to the EU's broader climate goals.

These policies encourage the development and adoption of low-emission and zero-emission vehicles, including electric and hybrid models, promoting technological innovation and cleaner transportation options.

Source: European Commission website

Electrification: Surge in Hybrid Vehicle Registrations

Trend Overview: Electrification of vehicles is a key trend in the automotive industry, significantly increasing the registrations of hybrid vehicles.



•**Statistics and Growth**:

- •Hybrid vehicle production has shown a rapid increase from 2020 to 2024 to meet the demands of early adopters.
- •**2024 growth pushed the hybrid-electric market share to 29.5%, up from 24.4% in June 2023**.
- •In the short term, hybrids with internal combustion engines (including micro hybrids) are projected to make up around 50% of vehicle production, while those that can use an electric motor for propulsion will account for almost 20%.

OEMs are expanding their portfolios to include more full and plug-in hybrids as a transitional solution towards full electrification.

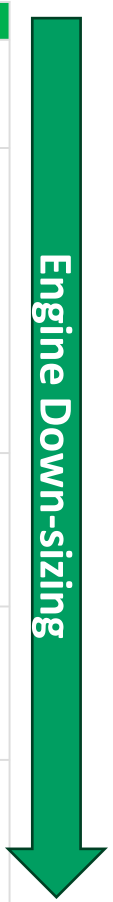
Source: ACEA

Performance Requirements for Hybrid Vehicle Engine Oils

Key Performance Factors

Hybrid vehicles are equipped with smaller ICE and often operate with frequent start-stop cycles and variable engine loads

Type	Energy source	Propulsion device
ICEV (Internal Combustion Engine Vehicle)	– 100% fuel (petrol/gasoline, diesel)	– 100% internal combustion engine
MHEV (Mild Hybrid Electric Vehicle)	– 80-90% fuel (petrol/gasoline, diesel) – 10-20% electrical energy	– 80-90% internal combustion engine – 10-20% electric motor
HEV (Hybrid Electric Vehicle)	– 70-80% fuel (petrol/gasoline, diesel) – 20-30% electrical energy	– 70-80% internal combustion engine – 20-30% electric motor
PHEV (Plug-in Hybrid Electric Vehicle)	– 60-70% fuel (petrol/gasoline, diesel) – 30-40% electrical energy	– 60-70% internal combustion engine – 30-40% electric motor
REEV (Range Extender Electric Vehicle)	– 80% electrical energy – 20% fuel (petrol/gasoline)	– 100% electric machine



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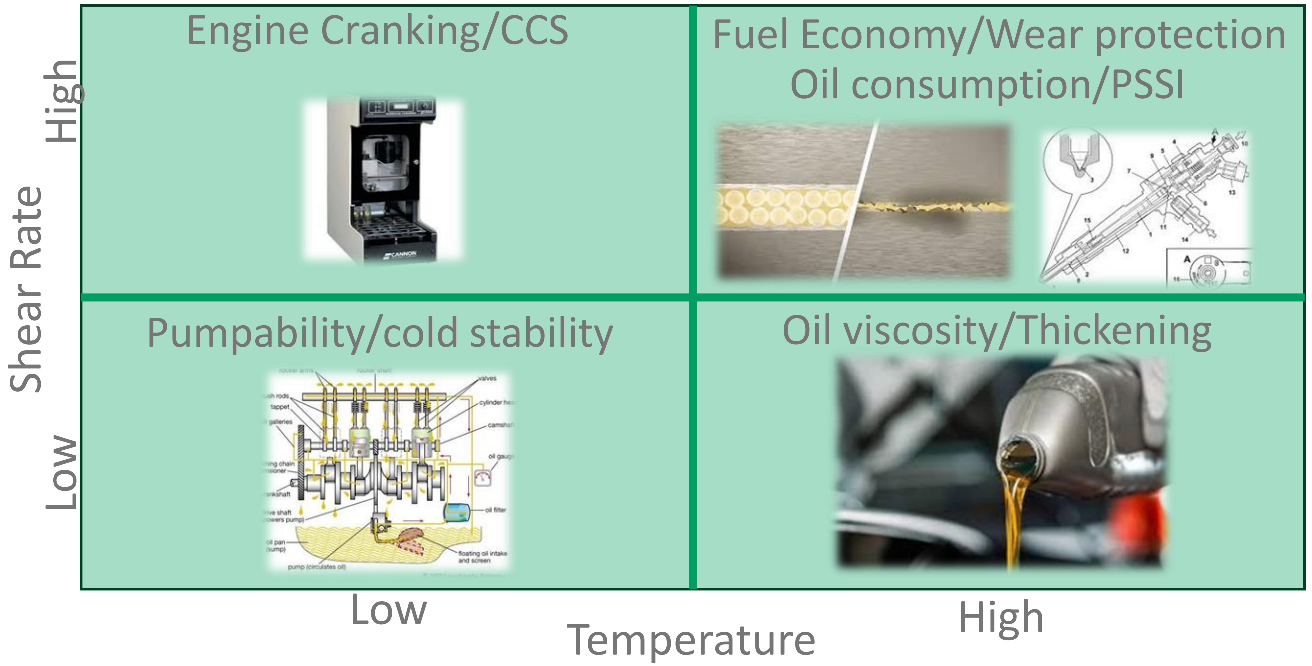
Engine Down-sizing

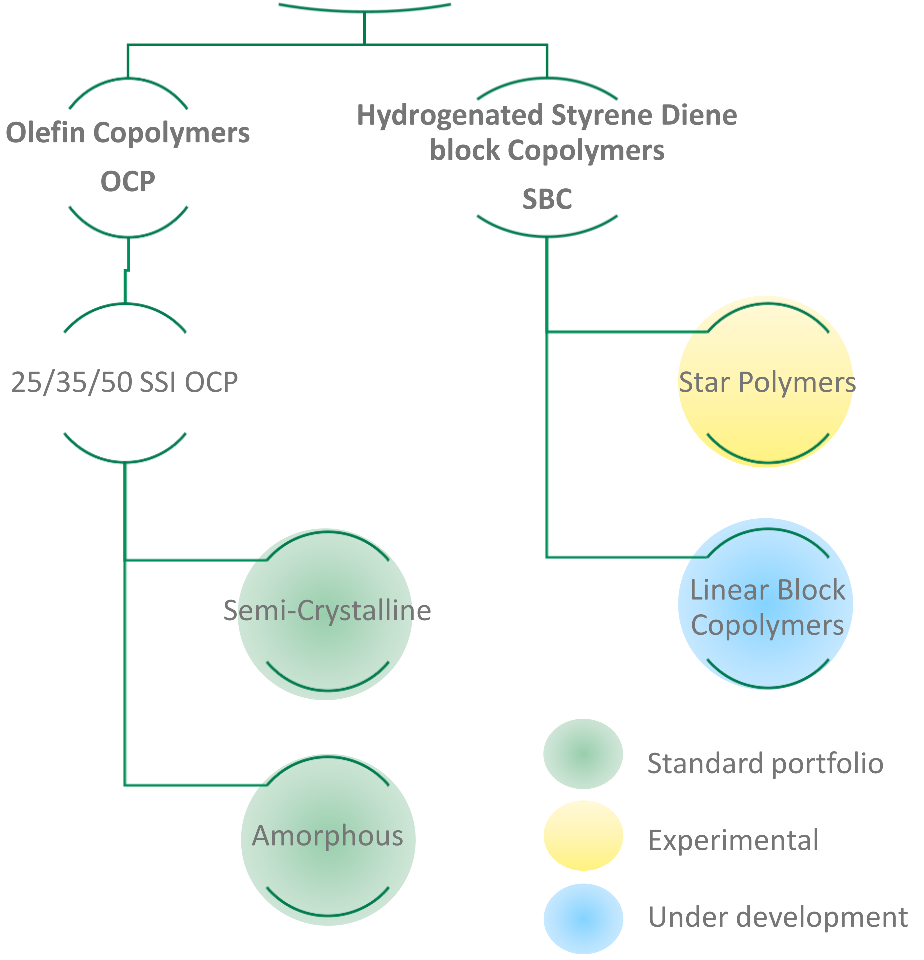
ICE in Hybrid vehicles working regime and design lead relative distance and contact morphology with specific characteristics in engines which require **lubricants capable to maintain optimal viscosity and stability under these conditions to ensure adequate lubrication and protection**



For engine oils to operate in the four types of shear rate and temperature parameters displayed, polymers for VII perform a crucial role.

Versalis Technological platform for VII

Viscosity Modifiers with highest consumption in engine oil modification

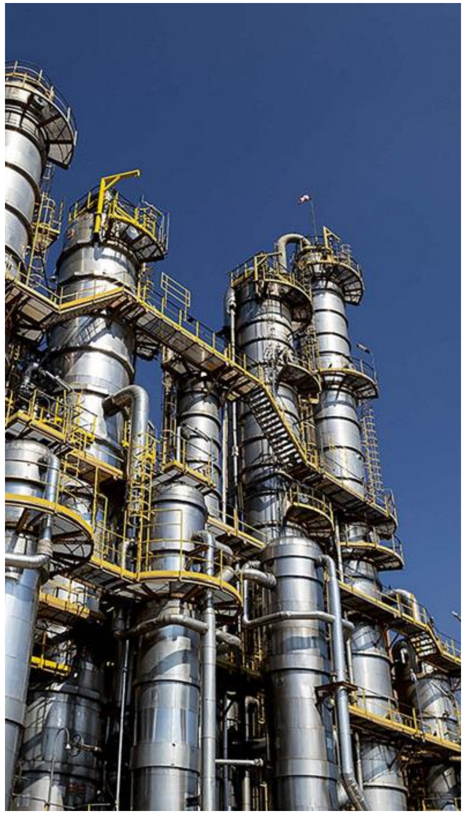


Linear olefin copolymers OCP

- Slurry process
- Ziegler-Natta Catalyst
- Thermo-mechanical treatment for low MW grades
- Ethylene-Propylene linear copolymers

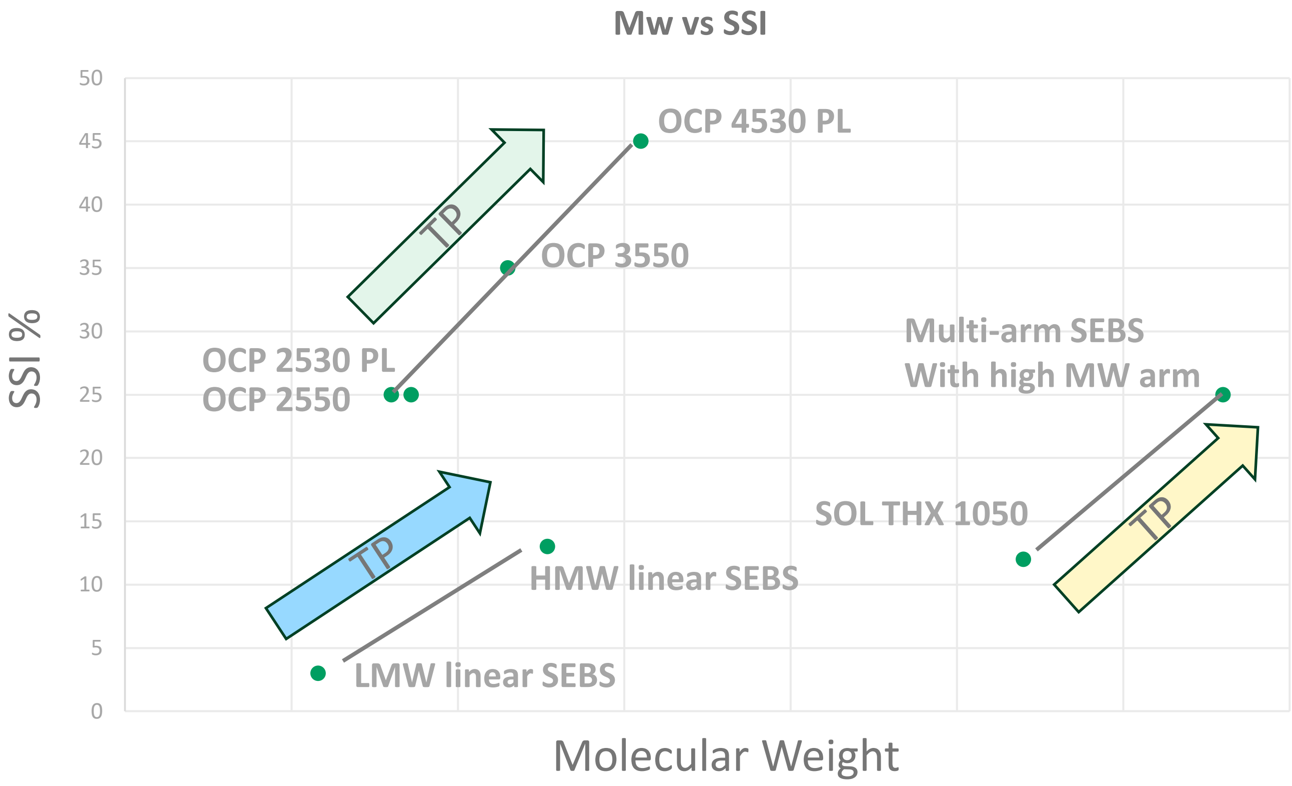
Thermoplastic elastomers SBC

- Solution process
- Living anionic polymerization
- Multi-arm or linear architecture
- Hydrogenated Styrene-Butadiene block copolymers



Oil thickening and polymer shear stability

TYPE		TP 1%w in SN 150 (cSt)
OCP Semi-crystalline	OCP 2530 PL	5,1
OCP Amorphous	OCP 2550	4,2
OCP Amorphous	OCP 3550	5,8
OCP Semi-crystalline	OCP 4530 PL	10,5
Star polymer	SOL THX 1050	4,2
Star polymer	Multi-arm SEBS HMW	5,5
Linear block copolymer	Linear SDH tri-block LMW	2,7
Linear block copolymer	Linear SDH2 HMW	4



TP: increases with higher molecular weight of the polymer, more effective for linear architectures.
For OCPs, polymers with same MW but higher ethylene content performs a higher TP.

SSI: For each polymer type, lower permanent Shear Stability is observed when Mw increase.
For multi-arm polymers, the particular architecture with central symmetry contributes beneficially to shear stability, as the breakage of the "side chains/arms" has less impact on the reduction of the “thickening” or volume occupied by the macromolecule compared to a breakage of the single linear polymer backbone.

Low temperature performance: High and Low shear rate

Test	Temperature	Shear rate (s^{-1})
CCS	Single point (-25°C)	10^5 to 10^4
Scanning Brookfield	Slope 1°C/h for 35h	0,25

- Despite the same viscosity-temperature behavior, oils containing different VIIs can exhibit different viscosity-shear rate characteristics.
- Concerning cold flow properties, startability and cold stability of multigrade engine oils have to be distinguished: whereas startability of engine oils can be simulated by CCS viscosities, a scanning Brookfield viscosity at near-zero shear rate has to be determined in order to describe cold stability.
- The degree of viscosity increase with decreasing shear rate depends on polymer concentration and on polymer type.
- Literature reports for OCPs and SBCs a sharply increase of viscosity with decreasing shear rates.

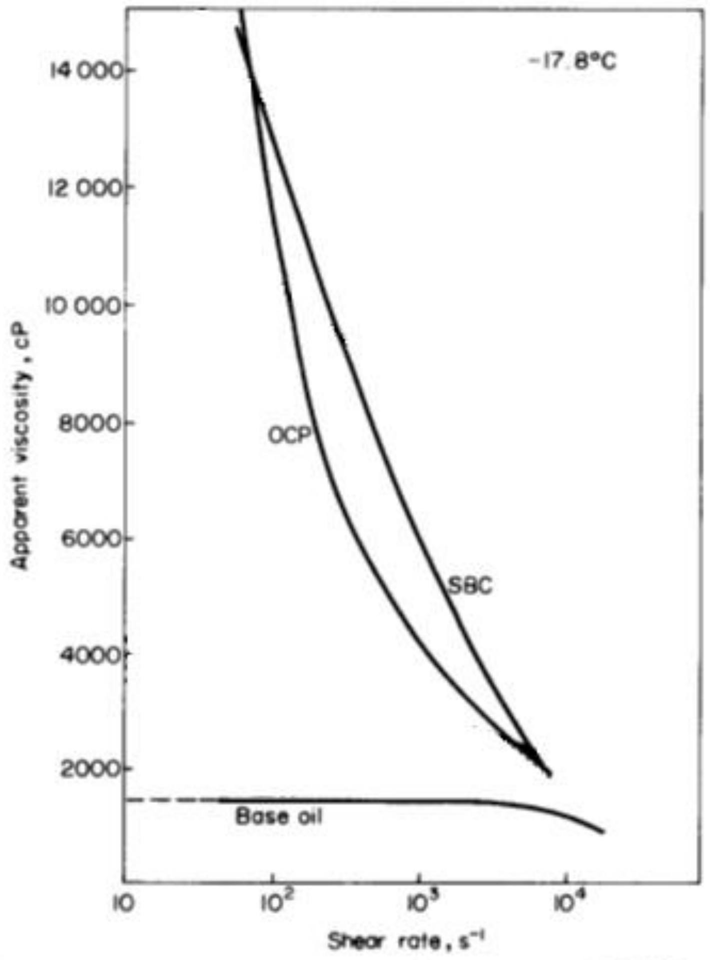


Fig 10 Apparent viscosity over shear rate at –17.8°C depending on polymer type.

Source: W.J. Batrz, TRIBOLOGY international, Feb. 1976

Low temperature performance: High and Low shear rate

- The results of high shear and low temperature (CCS) tests are quite aligned for the series of selected polymers, even with different TP, originating from very diverse synthetic chemistries.

- Particular attention must be paid to tests in which solutions are maintained at low temperatures and low shear (scanning Brookfield):

TYPE		CCS -25° 1%w in SN 150 (cP)	Gelation Index
OCP Semi-crystalline	OCP 2530 PL	5800	**10**
OCP Amorphous	OCP 2550	6050	6
Star polymer	SOL THX 1050	6070	6
Linear block copolymer	Linear SDH tri-block LMW	6320	**18**
Linear block copolymer	Linear SDH2 HMW	6200	6

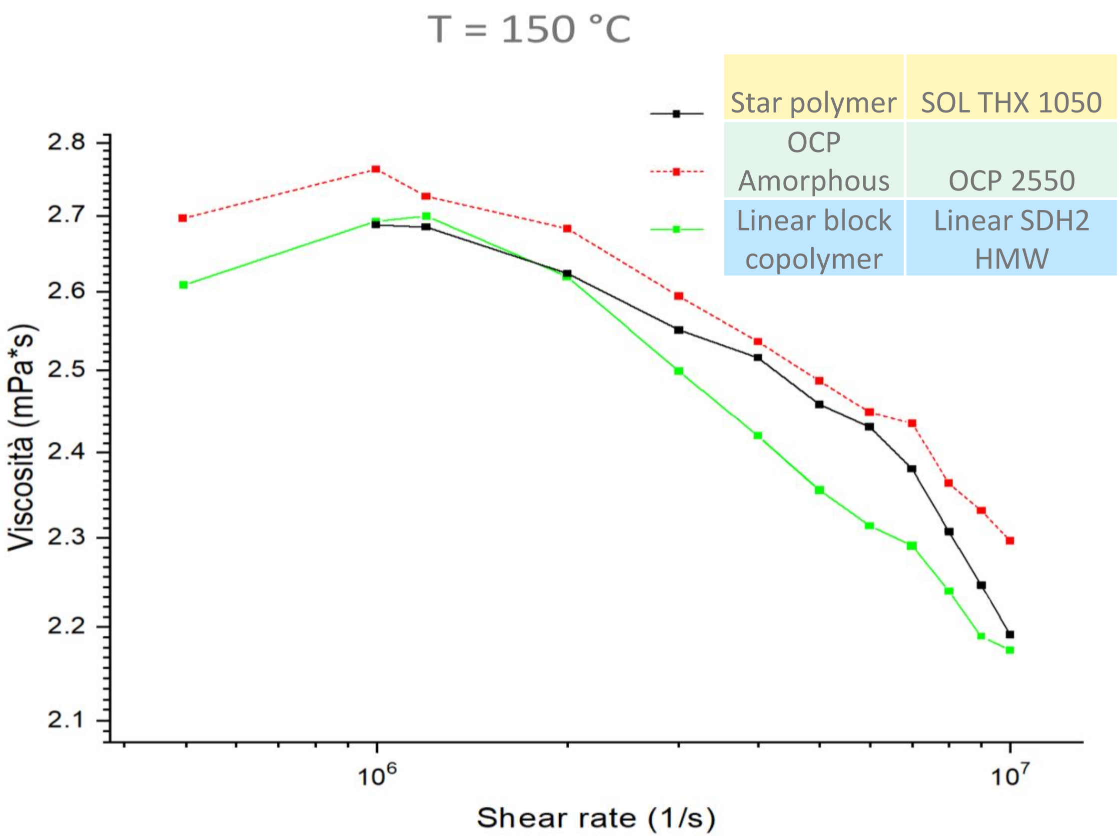
  - For OCPs, special attention must be given to polymers with higher ethylene content, which, depending on the formulation context, may have time to aggregate their crystalline component with waxes and paraffins present in the formulation that can be disaggregated under high shear or temperature.

  - An S-EB-S triblock at low temperature and low shear certainly constitutes a 3D network, which effect is not appreciable in CCS due to the breaking of weak bonds caused by the high shear imposed by the apparatus.

Fuel Economy vs Wear protection: High temperature High Shear

Equipment	PCS Ultra-Shear Viscometer
Shear rate	$0.5 \cdot 10^6$ 1/s – 10^7 1/s
Temperature	150°C

- Viscosity data are reported for highly dilute solutions at same targeted viscosity (10 cSt in SN 150).
- Under these conditions of high shear and temperature, all solutions exhibit non-Newtonian behavior and closer viscosity drops.
- Solution containing the linear SEBS prototype compared to the other three samples shows a slightly earlier shear thinning: This rapid decrease can be explained by disaggregation of micelles between polymer chains due to temperature and shear imposed.



Conclusion

- Despite similar viscosity-temperature behavior, polymer-modified oils can exhibit different viscosity-shear rate characteristics.

- For the development of OCP and SBC for VII applications, it is crucial to consider this behavior in oil to introduce products whose molecular weight, composition, architecture, and polarity positively respond to the four operational rheological windows of engine oils.

- Versalis and Eni R&D are cooperating to develop new Viscosity Index Improvers to comply with the utmost stringent specifications

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