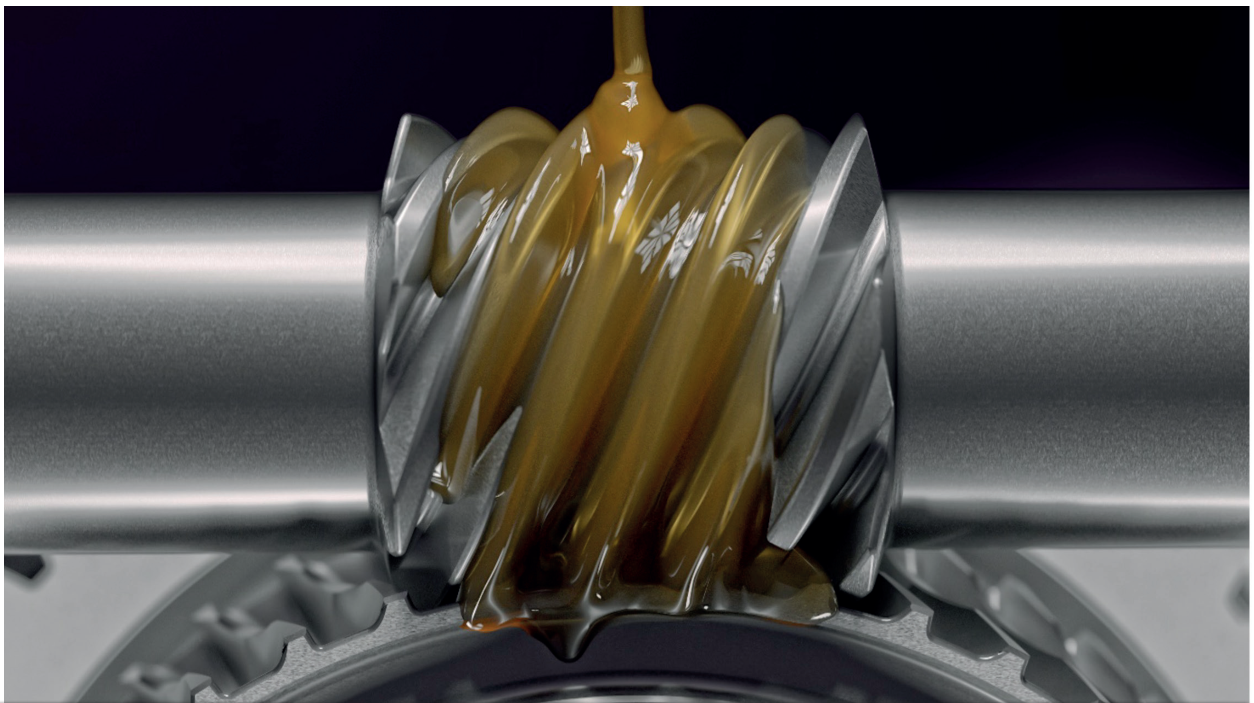

VISCOSITY MONITORING IS MORE OPERATIONALLY IMPORTANT FOR CIRCULAR FEEDSTOCKS

As recycled polymers and waste-derived oils continue to be developed, viscosity is becoming one of the quickest ways to see whether a feedstock will actually behave inside a plant.

For a long time, viscosity was treated as one useful property among many: important, certainly but rarely the headline variable. That is changing. In recycled plastics and waste-derived process oils, viscosity is increasingly where feedstock variability first becomes visible to operators. It is the point at which circularity stops being a procurement story and becomes a process-control story. Recent research on mechanically recycled polyethylene shows why: recycling histories, contamination and degradation all alter melt behaviour in ways that directly affect processability. At the same time, industrial players such as Neste are scaling up facilities to upgrade liquefied waste plastic into petrochemical feedstock, which raises the commercial value of fast, reliable ways to distinguish a manageable stream from a troublesome one.

The technical reason viscosity matters is straightforward. It is not merely a colloquial measure of how 'thick' something feels. In formal terms, dynamic viscosity expresses the relationship between shear stress and shear rate, while kinematic viscosity is the ratio of dynamic viscosity to density. The classical petroleum measurement route, still embedded in standards, is to let a liquid flow under gravity through a calibrated glass capillary and measure the time taken. ASTM D445-24 remains the core ASTM method for this, and ISO's corresponding family standard is ISO 3104, with ISO listing the 2020 edition as withdrawn and revised by ISO 3104:2023. Both standards also make the same critical point: these methods are primarily intended for liquids with Newtonian behaviour, and results can diverge when shear dependence becomes significant.

That caveat becomes crucial in circular feedstocks. In mechanically recycled polymers, viscosity is not just a flow property; it is also a proxy for what has happened to the material. The 2024 *Nature Communications* paper on polyethylene recycling links rheology to degradation pathways such as chain scission and branching, and stresses that real-world recyclate streams are made more unpredictable by compositional variability and contamination. In practical terms, that means viscosity drifts can signal changes in molecular architecture, not simply changes in line temperature or screw speed. For processors blending virgin and recycled material, that makes viscosity a highly attractive early-warning variable.

Waste-derived oils create a parallel problem from the liquid side. Pyrolysis and upgrading routes can produce streams that are chemically valuable but operationally awkward. The petrochemical question is not just whether such oils contain useful hydrocarbons, but whether they can be pumped, heated, blended, atomised and cracked without creating unacceptable instability. ASTM's new D8577-25 guide for waste plastic process oil analyses reflects this maturing reality. It sets out a minimum analytical framework for examining waste plastic process oils and explicitly includes physical properties and contaminants, rather than treating such streams as if they were already standardised refinery inputs. In other words, the industry is acknowledging that these materials need disciplined characterisation before they can be trusted.

This is why viscosity is becoming more important now than it was in a world dominated by virgin, relatively predictable feedstocks. In a conventional stream, viscosity is often one specification number among many. In a circular stream, it can function as an operational diagnostic. A drift in viscosity may point to altered feed composition, oxidation, contamination, degradation, wax content, temperature conditioning problems or blending error. Because viscosity also affects storage, handling and operational behaviour in petroleum products, it sits unusually close to day-to-day plant risk. ASTM D445 makes exactly that point in its significance and use section, noting that viscosity is essential for correct equipment operation and for estimating appropriate storage, handling and operating conditions.

> *In a circular stream, viscosity functions as an operational diagnostic*

That shift in meaning is driving a shift in measurement practice. The old model was sample first, answer later: take material to the lab, run a capillary test or a rheometer, and act after the fact. That is increasingly too slow for lines processing variable circular materials. The 2025 *Scientific Reports* paper on melt viscosity prediction in polymer extrusion describes melt viscosity as a key quality indicator and argues that offline measurement introduces a significant time lag between production and the identification of quality issues, leading directly to wasted material. The same paper notes that real-time control has been hampered by disturbances from in-line or sidestream rheometers and by measurement delays, which is why so much attention is now going into smarter measurement architectures.

So how is instrumentation changing? At one end, the classical laboratory backbone remains in place. Capillary methods such as ASTM D445 and automated approaches such as ASTM D7042, which covers dynamic viscosity and density by Stabinger viscometer with calculation of kinematic viscosity, still matter because they offer traceable, standardised QC data. They are especially useful when the aim is product release, supplier comparison or method alignment across sites. But they are still sample-based methods, and they still inherit the problem that low-shear, highly controlled tests do not necessarily represent what a non-Newtonian feedstock is doing inside a hot, pressurised, continuously moving process.

For non-Newtonian materials, rotational and capillary rheometry remain the best tools for understanding what viscosity actually means across a range of shear conditions. That is one reason recent recycling research leans so heavily on rheology rather than on a single-point viscosity value. Rheology can expose the signature of degradation and help distinguish one material history from another. But a bench rheometer is not, by itself, a plant control strategy. It is a characterisation tool. The operational challenge is translating that richer understanding into signals that can be trusted online.

This is where inline viscometers and resonant sensors come in. Suppliers such as Hydramotion now pitch polymer-melt viscometers directly into extruder ports and melt pipelines, emphasising real-time data, PLC or DCS integration, and closed-loop control. Their materials for polymer service focus on precisely the problems a petrochemical audience will recognise: high temperatures, high pressures, filled systems, scrap reduction and rapid response to raw-material variability. Rheonics makes a similar case, but with an additional technical emphasis that matters greatly in circular feedstocks: effective shear rate. Its guidance on torsional resonator sensors stresses that non-Newtonian fluids do not have one universal viscosity value, because different instruments interrogate them at different shear rates. That point is not academic. If the lab method and the inline sensor are effectively measuring different states of the fluid, then "method disagreement" may be built into the physics rather than caused by a faulty instrument.

That is also why soft sensors and machine-learning models are appearing alongside hardware rather than replacing it outright. The *Scientific Reports* study reported strong performance from a machine-learning-enhanced grey-box soft sensor for polymer extrusion, but it also highlighted a limitation highly relevant to recycled materials: such models can struggle when viscosity changes are driven by changes in material properties rather than by operating conditions alone. For circular feedstocks, that is a serious limitation, because material-property drift is exactly the problem. In practice, the likely direction of travel is a hybrid architecture: direct inline viscosity sensing where possible, model-based prediction for speed and redundancy, and offline rheology or standard viscosity testing for calibration and root-cause analysis.

The standards picture is evolving in parallel. ASTM D8577-25 is important because it gives the waste-plastic-oil segment a common analytical starting point, even if it is only a guide and explicitly does not cover end use. ASTM D7152-23 matters because circular blending problems are rarely linear; it provides recognised methods for calculating the viscosity of blends and the fractions needed to hit a target viscosity. ASTM D341-20(2025) remains relevant because viscosity-temperature relationships are central to handling, heating and blending decisions in hydrocarbon service. And for plants trying to correlate an inline process viscometer with an offline lab method, ASTM D6299 and D6708 are highly useful because they address statistical quality assurance and the expected agreement between two different test methods purporting to measure the same property.

The regulatory picture is less about a single viscosity rule than about tightening quality expectations around circular materials. Neste's Porvoo project is revealing in this respect. The company says the new upgrading facility is designed to close the quality gap between crude liquefied plastic waste and the drop-in raw materials required by the petrochemical industry, and it also notes that production ramp-up depends on market and legislation development. That combination tells its own story. Once circular feedstocks move into mainstream refinery and petrochemical assets, the burden of proof shifts decisively towards consistent, auditable quality control. Viscosity is unlikely to be the only gatekeeper, but it is increasingly one of the fastest and most operationally meaningful ones.

A recycled polymer melt does not reward the same measurement assumptions as a clean Newtonian laboratory liquid. A waste-derived oil that may contain unstable fractions, contaminants or variable density does not reward casual reliance on a single offline number. The smarter plants will treat viscosity as a system problem involving shear rate, temperature control, installation geometry, fouling management, method correlation and automation integration. In circular feedstocks, the winning measurement strategy will be one in which operators know, early enough to matter, whether the material in front of them is about to behave erratically.

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