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abstract

The evolution of the European laundry market into cold and quick wash using an ever-increasing array of product formats is accelerating the need for inclusion of effective anti-redeposition agents to maintain fabric whiteness and color-integrity. Carboxymethyl cellulose, a predominantly biobased, biodegradable and non-hazardous biopolymer, provides an effective solution. Suitable for use in both liquid and powder formats, these weight efficient ingredients provide the formulator with more sustainable and non-persistent functionality to meet and exceed household consumer laundry performance expectations.

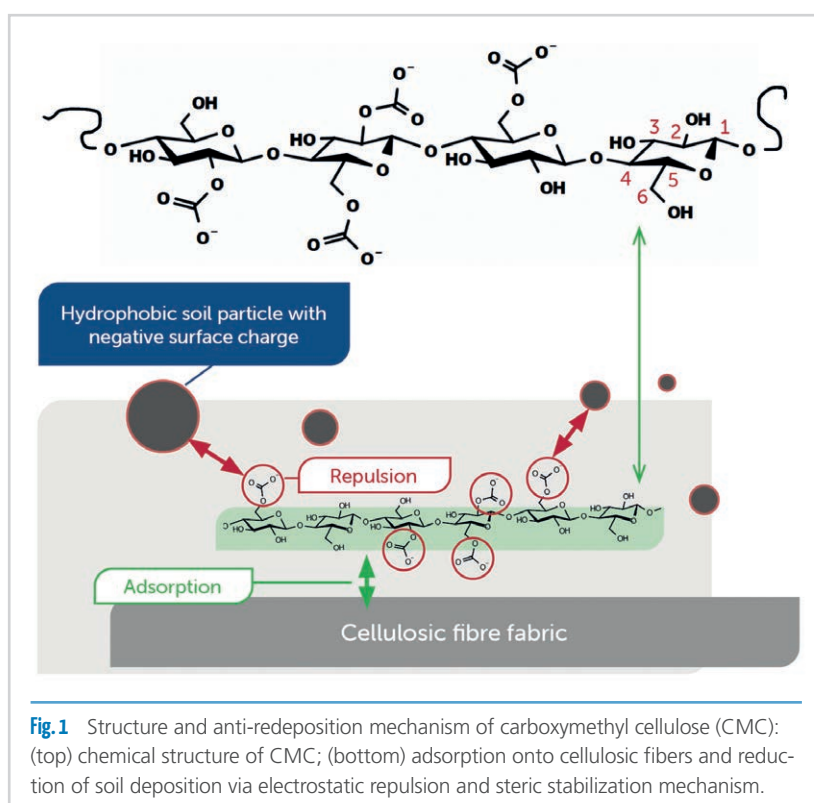
Introduction

Cellulose, the most abundant biopolymer on Earth, represents a renewable and versatile raw material for industrial applications, including detergent formulations. Unlike many other bio-derived polymers (e.g., starch), cellulose is not suitable for human consumption, thereby avoiding competition with food resources,[1] while its chemical functionality and inherent affinity for cellulosic substrates make its derivatives particularly effective for fabric care applications.

During laundering, soils are removed from fabrics and dispersed into the wash liquor; however, without adequate stabilization, soils may redeposit onto textile surfaces, leading to greying and dulling. Anti-redeposition (ARD) agents mitigate this by stabilizing soil particles in suspension and modifying the fabric surface to reduce soil adhesion. This function is particularly important for hydrophobic particulate soils and under low-temperature washing conditions, where cleaning efficiency is reduced. Concurrently, there is growing demand for ARD solutions that combine high performance with improved sustainability, driving interest in biobased and biodegradable alternatives to conventional synthetic polymers.

For decades, carboxymethyl cellulose (CMC) has been used as an ARD agent in powder detergents due to its affinity for cellulosic fibers such as cotton, linen, and viscose. The introduction of anionic substituents along the cellulose backbone promotes electrostatic repulsion between fiber surfaces and soil particles, thereby reducing redeposition from the wash liquor (Fig. 1).

Despite this established functionality, CMC performance varies significantly depending on its structural characteristics. Key parameters, including molecular weight, degree of substitution (DS), and substitution pattern, can strongly influence solubility, adsorption behavior and ARD efficiency. These parameters are governed by reaction conditions and process design, offering opportunities to tailor performance for specific detergent applications.



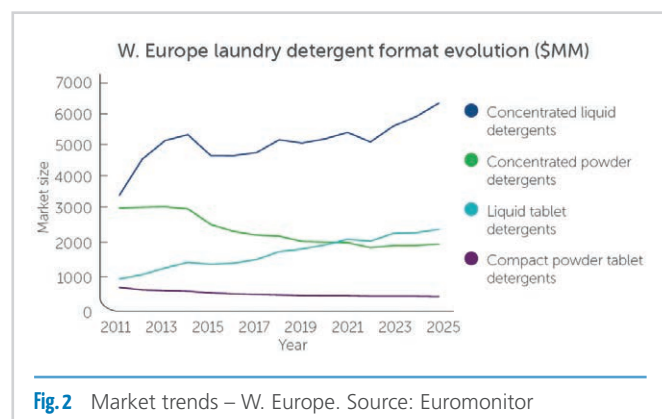
CMC properties are primarily governed by molecular weight and DS. The cellulose backbone consists of anhydroglucose units, each containing three hydroxyl groups (positions 2, 3, and 6, **Fig. 1**), which can undergo nucleophilic substitution with monochloroacetic acid. Although the reaction is not regioselective, differences in reactivity lead to a distribution of mono-, di-, and trisubstituted anhydroglucose units across the polymer chain. Where the overall DS represents an average value, the underlying substitution pattern influences key material properties. Control of the substitution pattern through process optimization enables tuning of CMC performance.[2-5]

CMC remains a widely used and commercially relevant ARD technology in powder detergents due to its ease of incorporation and high efficiency at low dosage levels. Continued optimization of CMC chemistry has further improved its weight efficiency, enabling modern grades to deliver equivalent or superior performance at significantly reduced dosage compared to earlier materials.

Throughout much of the modern household laundry era, laundry powders have dominated the European market both in terms of volume and value of detergents sold. In the early 21st century however, this balance has shifted towards novel formats that appeal to consumer preferences and lifestyles.

From about 2010, laundry liquid sales eclipsed that of laundry powders in Western Europe for the first time (**Fig. 2**). This divergence continues, with laundry liquid sales continuing to trend upward, whilst laundry powder sales flagged.

The other major new entrant to the market is liquid tablet detergents, which include pods, capsules and unit dose. The highly concentrated PVA-wrapped liquid laundry format was nascent in 2011 but has since proven popular with consumers and continues to show marked growth, itself overtaking powder sales in value terms from around 2021. However, this rise in liquid laundry and unit dose formats has posed a challenge to traditional CMC products, which until now have shown incompatibility in liquid laundry formats.



The other market driver that favors CMC chemistry is the preference for bio-based, biodegradable, and low product carbon footprint solutions. CMC not only meets these requirements, but has no hazard classification, making it suitable for modern detergent systems across wash temperatures.

Methods

The ARD performance of polymer additives was evaluated using a controlled laboratory screening method designed to quantify the ability of detergent systems to prevent soil deposition onto textile substrates. The method is optimized for high sensitivity and reproducibility by introducing greasy particulate soil directly into the wash liquor.

Principle of the Method

Soil is dispersed in the wash bath and deposition onto initially clean fabrics is monitored. Performance is quantified as the change in fabric whiteness (ΔCIE , D65/10° + UV) between the initial and the post-wash states. To enable comparison, the results of polymer-containing samples are referenced against a formulation without polymer. Higher ΔCIE values indicate improved antiredeposition performance.

Lamp black is used as the model soil, representing a hydrophobic particulate soil system. Due to its surface characteristics and fine particle size, it presents a challenging redeposition scenario with tendency to aggregate and redeposit. The method probes both dispersion and prevention of deposition at the fiber–liquid interface.

Preparation of Test Substrates

White knitted cotton swatches (5 × 5 cm) were pre-treated by washing at 60 °C in a detergent-free cotton cycle to remove residual finishing agents. Swatches were air-dried, ironed, and stored protected from light prior to testing. Initial whiteness was measured spectrophotometrically to establish a baseline.

Wash Procedure

Experiments were performed using a Terg-O-Tometer under controlled cold wash conditions. For each test, 800 mL of hard water (18 °dH) was equilibrated at 25 °C. Polymer solutions were added and mixed for 5 minutes, followed by eight clean swatches, conditioned for an additional 5 minutes. Lamp black (320 mg) pre-wetted with ethanol to ensure dispersion was then added, followed by the detergent formulation. Washing was performed for 60 minutes at 200 rpm.

Swatches were subsequently rinsed in fresh water of identical hardness for 15 minutes at 200 rpm, air-dried overnight and ironed prior to analysis.

Final reflectance was measured using a spectrophotometer (Konica Minolta CM3600d). ARD performance was expressed as Δ CIE whiteness between initial and final measurements. All samples were tested in replicates, and results are reported as mean values.

Results and Discussion

Performance of Optimized CMC Grades vs. Conventional CMC

The performance of two structurally optimized CMC grades (optimized, purified CMC and optimized, technical CMC) was evaluated in a powder detergent system, where CMC is traditionally used as an antiredeposition agent (Fig. 3). Both optimized grades demonstrated a clear increase in Δ CIE whiteness with increasing dosage, outperforming conventional technical CMC across the full concentration range.

The optimized, purified grade showed the highest performance, followed by technical optimized grade, while the conventional CMC exhibited significantly lower efficiency. Notably, the optimized grades achieved comparable or superior performance at lower dosage levels, highlighting improved effectiveness per unit of active polymer. These results demonstrate that structural optimization of CMC enables enhanced ARD performance in powder detergents, where fiber affinity and redeposition control are critical functionality drivers.

Extension of Optimized CMC Performance to Liquid Laundry Systems

Incorporation of CMC into liquid laundry formulations has historically been limited by solubility and phase stability challenges. Advances in CMC design now enable compatibility with modern heavy-duty liquid detergents, allowing this long-established ARD technology to be extended from powder into liquid formats. Conventional CMC exhibits phase separation in a commercial liquid detergent system (1 % ac-

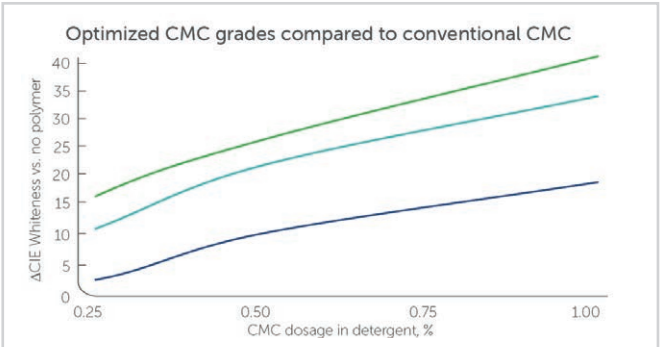


Fig. 3 Anti redeposition performance of optimized CMC grades compared to conventional CMC: Δ CIE whiteness (vs. no polymer reference) as a function of dosage, showing enhanced efficiency of optimized CMC grades over conventional CMC.

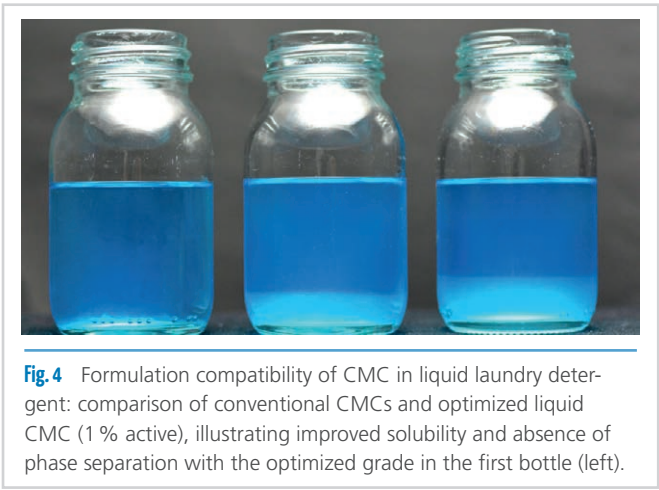


Fig. 4 Formulation compatibility of CMC in liquid laundry detergent: comparison of conventional CMCs and optimized liquid CMC (1 % active), illustrating improved solubility and absence of phase separation with the optimized grade in the first bottle (left).

tive), whereas optimized CMC forms stable, homogeneous formulations (Fig. 4).

This development enables the combination of proven performance and improved sustainability within liquid laundry formulations without compromising stability or efficacy.

Benchmarking against Commercial ARD Polymers in HDL Formulations

While CMC is well established in powder formulations, its use in heavy-duty liquid (HDL) detergents has been limited by solubility and formulation compatibility constraints. Optimized CMC grade overcomes these limitations, enabling extension of this chemistry into liquid systems while retaining the inherent fiber affinity and antiredeposition efficiency. Optimized liquid CMC was benchmarked against commercial polymeric ARD additives at equal dosage (1 % active) in a commercial

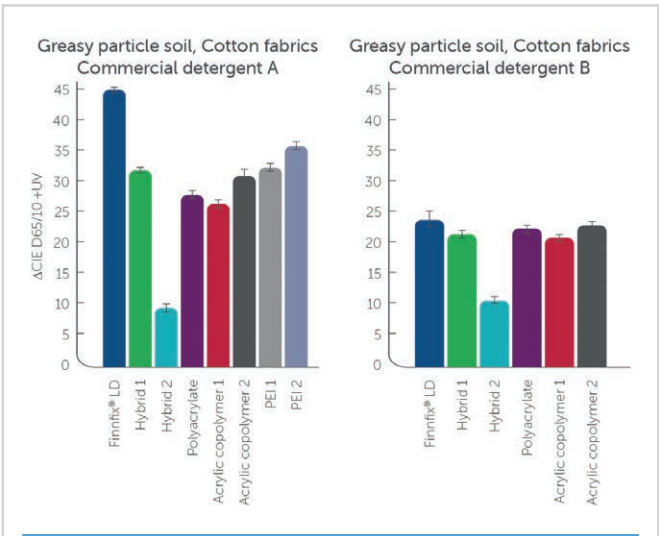


Fig. 5 Benchmarking of optimized CMC against commercial ARD polymers in heavy-duty liquid detergents: (A) Commercial detergent A; (B) Commercial detergent B. Δ CIE whiteness (vs. no polymer reference) measured using a hydrophobic particulate soil system, demonstrating superior performance of optimized CMC relative to synthetic and hybrid polymer technologies.

HDL formulation without an ARD agent. Performance was evaluated by Δ CIE whiteness. As shown in Fig. 5, optimized CMC outperformed all tested polymers.

Across both detergent systems (Fig. 5A-B), CMC consistently showed higher performance than synthetic and partially biobased polymers. This is notable given the use of hydrophobic particulate soil, where synthetic polymers such as polyacrylates and polyethylene imine (PEI) would generally be expected to perform well. However, CMC delivered superior results. Importantly, this trend was reproducible across multiple HDL formulations, supporting the robustness and general applicability of the observed effect.

In addition to performance, CMC offers a clear sustainability advantage. Unlike synthetic polymers, derived from non-re-

newable resources, CMC is produced from renewable cellulose, is biodegradable, and has a lower carbon footprint. Optimized CMC therefore combines superior technical performance with a strong environmental profile.

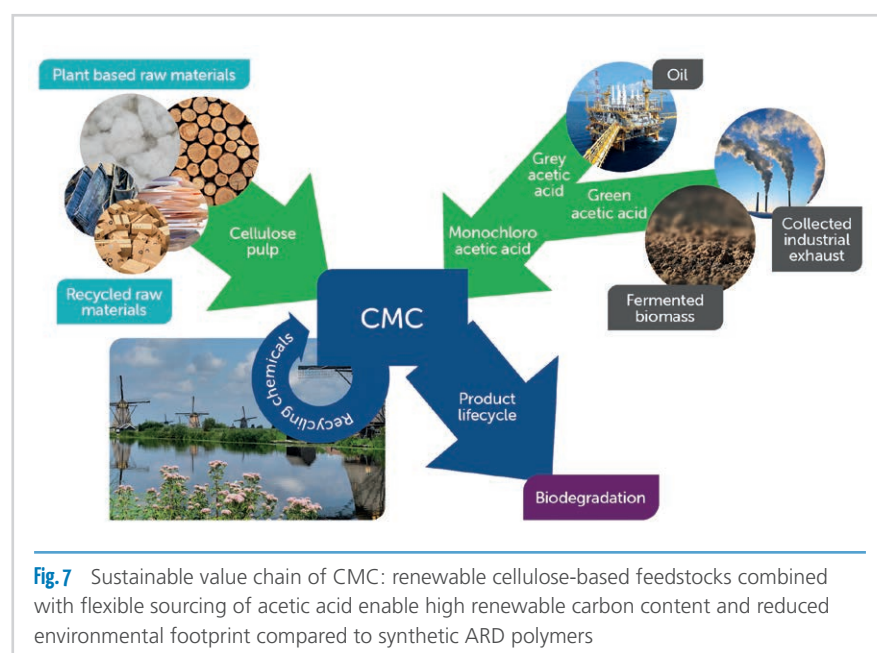
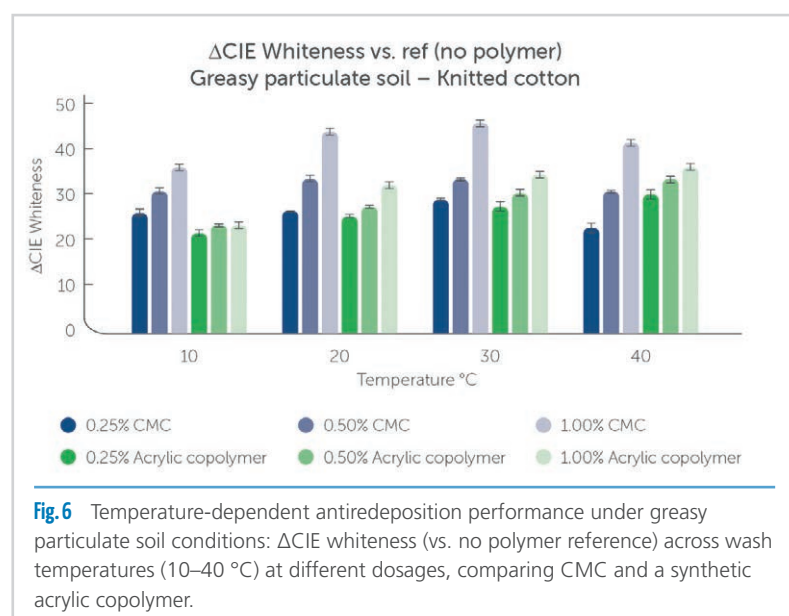
Performance across Wash Temperatures (Applicability to Powder and Liquid Systems)

Optimized CMC maintains consistently high ARD performance across a full temperature range (10–40°C), enabling effective cleaning both cold and warm wash conditions (Fig. 6). Performance was benchmarked against a synthetic polyacrylic acid copolymer at equal dosage (1 % active).

Optimized CMC delivers stable Δ CIE whiteness across temperatures, with only minor variation, whereas the acrylic copolymer shows a clear dependence on temperature, with significantly reduced performance under cold wash conditions and improved performance at higher temperatures. This highlights the robustness of CMC, particularly where soil removal and dispersion are more challenging.

The temperature-independent behavior of CMC can be attributed to its adsorption onto cotton fibers, forming a hydrated, negatively charged layer that inhibits soil redeposition via electrostatic and steric effect. This mechanism remains effective at low temperatures, where surfactant-driven soil dispersion is limited.

At higher temperatures, increased surfactant activity enhances soil removal, while CMC stabilizes dispersed soil particles. In contrast, acrylic polymers primarily act in the bulk solution and show limited fiber affinity, resulting in reduced surface protection under cold conditions.



Sustainability Advantages of CMC as an ARD Agent

Carboxymethyl cellulose is well positioned from a sustainability perspective, being primarily derived from renewable, plant-based cellulose sourced from abundant biomass (Fig. 7). The second key raw material, monochloroacetic acid, can be produced via routes with varying environmental footprints. Its precursor, acetic acid, may originate from fossil sources or alternatively from biobased fermentation or recovered industrial emissions, enabling improvement of the overall sustainability profile. As a result, even conventional CMC exhibits a high renewable carbon index (RCI), typically

above 80 %, with potential to approach 100 % depending on raw material selection.

The CMC products described here are inherently biodegradable and predominately biobased, while offering a substantially reduced product carbon footprint, even 75 – 85 % lower than that of conventional synthetic ARD agents.

Compared to synthetic polymers, CMC combines high renewable content, biodegradability, and lower environmental impact. These attributes, together with strong technical performance, support its use in more sustainable detergent formulations. Its effectiveness at cold wash also contributes to indirect energy savings.

In addition, modern CMC grades benefit from improved weight efficiency as significantly lower dosages are required to achieve the same ARD performance as earlier materials. This reduces formulations carbon footprint, packaging and product weight.

Conclusions

This work demonstrates that structural optimization of CMC significantly improves ARD performance across detergent formats. Optimized grades outperform conventional CMCs in powder formulations, confirming the importance of controlled molecular structure and substitution.

Advances in CMC design also enable compatibility with modern HDL formulations, overcoming solubility and stability limitations and extending this well-established technology into liquid and unit dose formats.

Benchmarking against commercial polymers demonstrates superior performance of optimized CMC, even with demanding hydrophobic particulate soils. The use of lamp black highlights the importance of interfacial effects, as direct addition to the wash liquor emphasizes soil deposition onto clean fabrics. Under these conditions, optimized CMC outperforms synthetic polymers, indicating that polymer-fiber interactions and surface protection can outweigh bulk dispersion mechanisms. Optimized CMC maintains robust performance across wash temperatures, with stable whiteness retention even under cold wash conditions, supporting energy efficient laundry practices.

In addition to performance, CMC offers a compelling sustainability profile, combining high bio-based content, inherent biodegradability, and a significantly lower carbon footprint compared to synthetic alternatives.

Overall, optimized CMCs provide high-performance, versatile, and sustainable ARD solutions aligned with the evolving requirements of modern laundry formulations.

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