From Batch to Continuous Systems: Process-Intensified Production of TEMPO-Oxidized Cellulose Nanofibrils (CNFs)

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Introduction

CNFs combine high mechanical performance, renewability, and tunable surface chemistry, enabling applications in environmental remediation

CURRENT LIMITATION

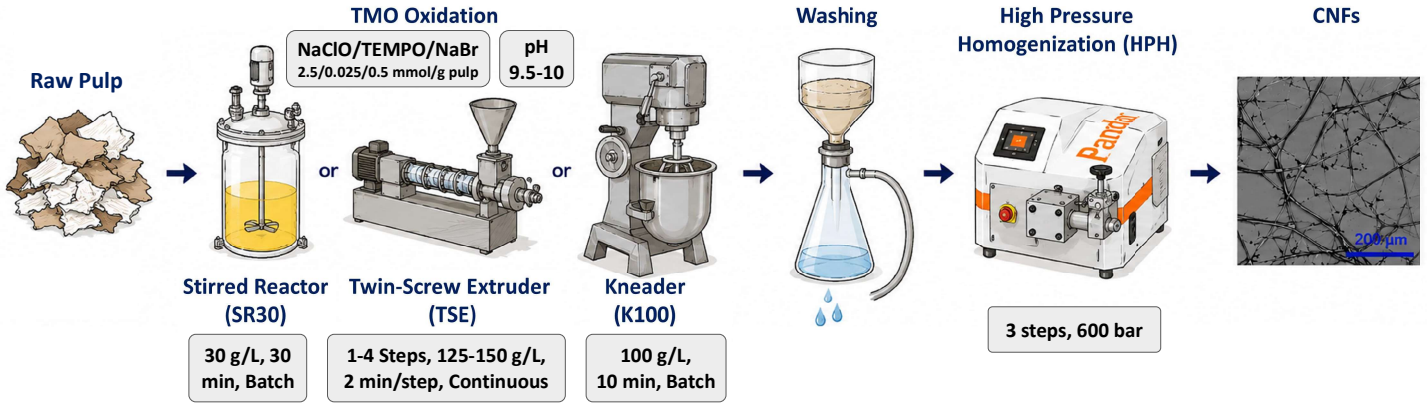
TEMPO-mediated oxidation (TMO) is an efficient pretreatment for CNF production, but conventional batch stirred reactors operate al low consistency, leading to high water consumption, low productivity, difficult scale-up or large reactor volumes

PROCESS INTENSIFICATION STRATEGY

This work evaluates high-consistency TMO in intensified reactor configurations: Batch kneader (K100) and continuous twin-screw extruder (TSE) as scalable alternatives to conventional stirred reactors

OBJECTIVE To compare conventional and intensified TMO configurations for the production of oxidized pulps and CNFs from different lignocellulosic feedstocks

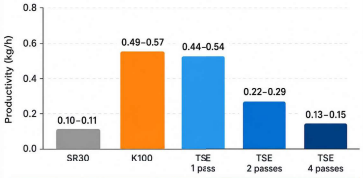
Methodology



Results

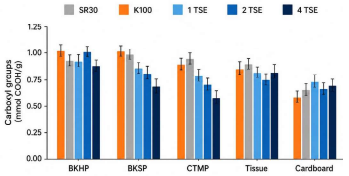
1. PROCESS INTESIFICATION INCREASE PRODUCTIVITY

K100 and TSE 1 pass achieved the best comprise between oxidation efficiency and productivity with substantial reduction of water usage and effluents generated



UP TO 5× HIGHER PRODUCTIVITY with intensified systems

2. INTENSIFIED REACTORS ACHIEVED OXIDATION LEVELS COMPARABLE TO BATCH SYSTEMS

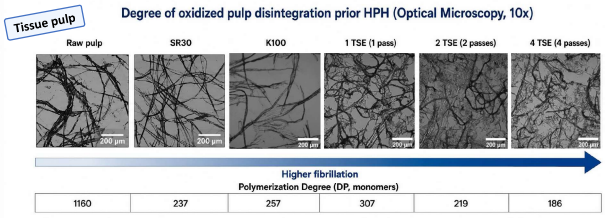


0.7-1.0 mmol COOH/g achieved in all configurations and feedstocks

Virgin pulps showed the highest oxidation efficiency

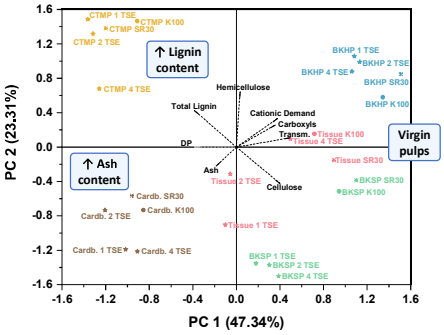
3. TSE PROMOTED HIGHER FIBRIL DISINTEGRATION

Multiple TSE passes increased fibrilation and reduce PD



4. FEEDSTOCK COMPOSITION WAS THE DOMINANT FACTOR GOVERNING CNF PROPERTIES

PCA analysis demonstrated that samples clustered mainly according to raw material type rather than reactor configuration used for pulp oxidation



Conclusions

High-consistency TMO is a viable strategy for scaling up CNF production for environmental applications

Kneader and TSE significantly increase productivity while reducing water consumption

Comparable oxidation levels were achieved relative to conventional stirred reactors

Raw material composition is the main factor controlling CNF properties

TSE enables continuous, high-consistency operation with high capacity and reduced microfiber content

Pilot-scale TMO maintains oxidation efficiency and fiber quality comparable to laboratory conditions

Acknowledgments

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