REMOVAL OF INSOLUBLE ADDITIVES FROM POLYSTYRENE BY APPLYING CENTRIFUGATION IN SOLVENT-BASED RECYCLING

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Introduction

Due to the wide range of applications and formulations of polystyrene (PS), its recycling presents several challenges. In particular, rubber particles and pigments can reduce the quality and market value of recycled PS, especially when mechanically recycled. Solvent-based recycling represents a promising alternative, enabling the recovery of high-quality polymer while facilitating the removal of insoluble additives and contaminants. This study investigates centrifugation as a separation technique for additive removal from PS solutions.

METHODOLOGY

AIM & SYSTEM DEFINITION

AIM

Assess centrifugation as separation technique for the removal of insoluble additives from PS solutions and evaluate the effect of key physicochemical and operational parameters on separation efficiency

SYSTEM DEFINITION

- Additives: TiO_2, carbon black, yellow pigment (Cr/Sb/Ti oxide), $CaCO_3$, and rubber particles of HIPS
- Solvents: limonene, o-xylene, and geranyl acetate
- Polymer concentrations: 1 wt%, 5 wt%, 10 wt%
- Centrifugal force: 3000 G, 6000 G, 12000 G
- Residence time: 1 min, 5 min, 10 min

DoE

- Total combinations: 405 (5 additives x 3 solvents x 3 polym. conc. x 3 centr. force x 3 res. time)
- Independent factors: polymer solution viscosity and density, polymer concentration, density and size of the additives, centrifugal force, and residence time
- Response: turbidity reduction of the supernatant (before vs. after)
- Full quadratic model with interaction terms was considered:

$$y = a_0 + \sum_{i=1}^{k} a_i X_i + \sum_{i=1}^{k} a_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} a_{ij} X_{ij}$$

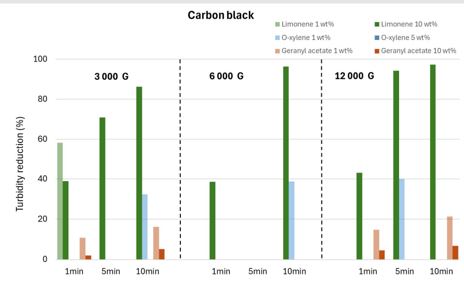
- I-optimal design chosen to identify optimal operating conditions
- Nr. of experimental runs determined based on statistical power (≥ 0.8)

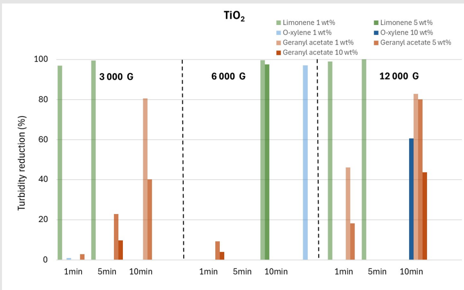
EXPERIMENTAL PROCEDURE

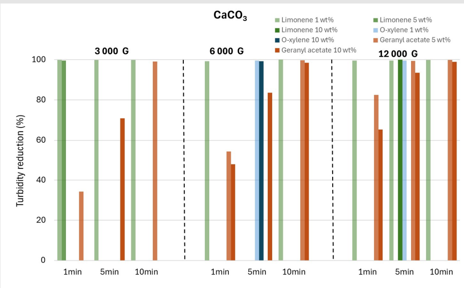
- Compounded polymer (with 1 additive) dissolution in the selected solvent for the chosen concentration, at RT with stirring for at least 8h
- Centrifugation of 10 mL of prepared solution with defined centrifugal force and residence time
- Separation of the supernatant after centrifugation
- Turbidity measurement of the supernatant
- Calculation of turbidity reduction

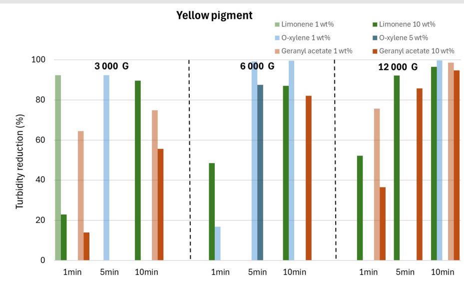
RESULTS

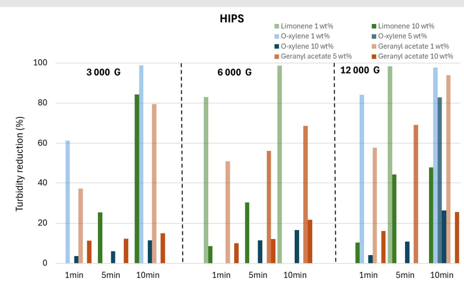
EXPERIMENTAL







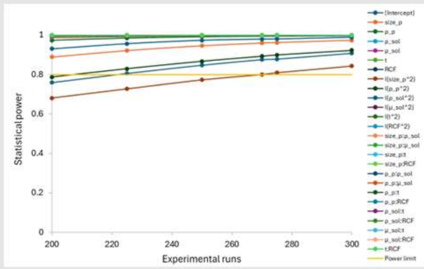




- Best solvent (higher turbidity reduction along all additives) is limonene (lowest viscosity)
- Best additive (higher turbidity reduction at lower G) is $CaCO_3$
- Worst solvent (lower turbidity reduction along all additives): geranyl acetate (highest viscosity)
- Worst additive (lower turbidity reduction at high G) PB beads from HIPS (lowest density difference with the solvent)
- $CaCO_3$, yellow pigments, and TiO_2 achieve high turbidity reduction (>80–99%) at 1 wt% and 3000 G with 1–10 min, depending on solvent. Higher concentrations require longer times or higher G for similar removal.

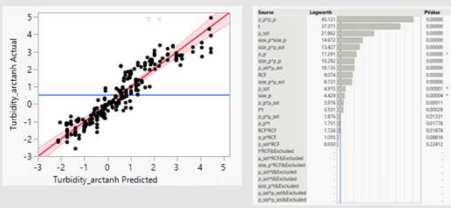
DoE

SELECTION OF EXPERIMENTAL RUNS NUMBER



270 was chosen as number of experimental runs because granted a statistical power ≥ 0.8 for all the terms of the quadratic model

MODEL REGRESSION



- Residuals showed a sigmoid shape due to 0–100% turbidity limits, so an arctanh transformation was applied for the model fitting
- The model was refined by removing non-significant effects ($p > 0.05$) while monitoring RMSE to ensure model performance
- The strongest contributors to turbidity reduction are linear terms (time, G, viscosity) and a few quadratic terms (density and size of the additive). Only select two-way interactions (size·viscosity, density·viscosity of solution) are significant
- Model performance: RMSE = 11.65, adjusted R^2 = 0.88 (values back-transformed to original 0–100% turbidity reduction scale)

Conclusions

This work was financially supported by Flanders Innovation & Entrepreneurship (VLAIO) under the Moonshot cSBO Renovate and the ICON project Remove2Reclaim.

- A full quadratic model with interactions, designed via an I-optimal design, provided good predictive ability with RMSE = 11.65 and adjusted R^2 = 0.88
- Linear factors such as residence time, centrifugal force, and solution viscosity have the strongest influence on turbidity reduction. Select quadratic terms (additive density and size) and a few two-way interactions (size·viscosity, density·viscosity of solution) also contribute
- Limonene (lowest viscosity) and $CaCO_3$ (highest density difference) showed the highest removal efficiency, while geranyl acetate and PB beads were the most difficult systems

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