Supplemental Material

Transforming Decentralized Wastewater Treatment with Fibrous Super-Bridging Agents

Mathieu Verhille[1], Emilia Tognetty[1], Manel Mebarki[1], Lovenie Victor[1], Masashi Kaneda[2], Owen Armstrong[2], Nathalie Tufenkji[2] and Mathieu Lapointe[1]*

[1]University of Québec – École de technologie supérieure, Montréal, Québec, H3C 1K3, Canada

[2]Department of Chemical Engineering, McGill University, Montreal, QC, H3A 0C5, Canada

* Corresponding Author

* E-mail: mathieu.lapointe@etsmtl.ca

5 Pages, 1 Equation, 2 Figures, 4 Tables

$$NTU = c + \frac{d - c}{1 + \exp(b(\log(Al) - \log(e)))}$$

Where :

- c = the minimum value
- d = the maximum value
- e = the point of inflection
- b = Hill’s slope of the curve

Eq S1. Four-parameter log-logistic model, Dose–response relationships were modeled using a four-parameter log-logistic function. The alum concentration required to achieve 25 NTU was derived from the fitted models. Uncertainty was assessed via non-parametric bootstrap resampling (1,000 iterations). Rare convergence failures (<1%, only 2 iterations) were excluded from the analysis.

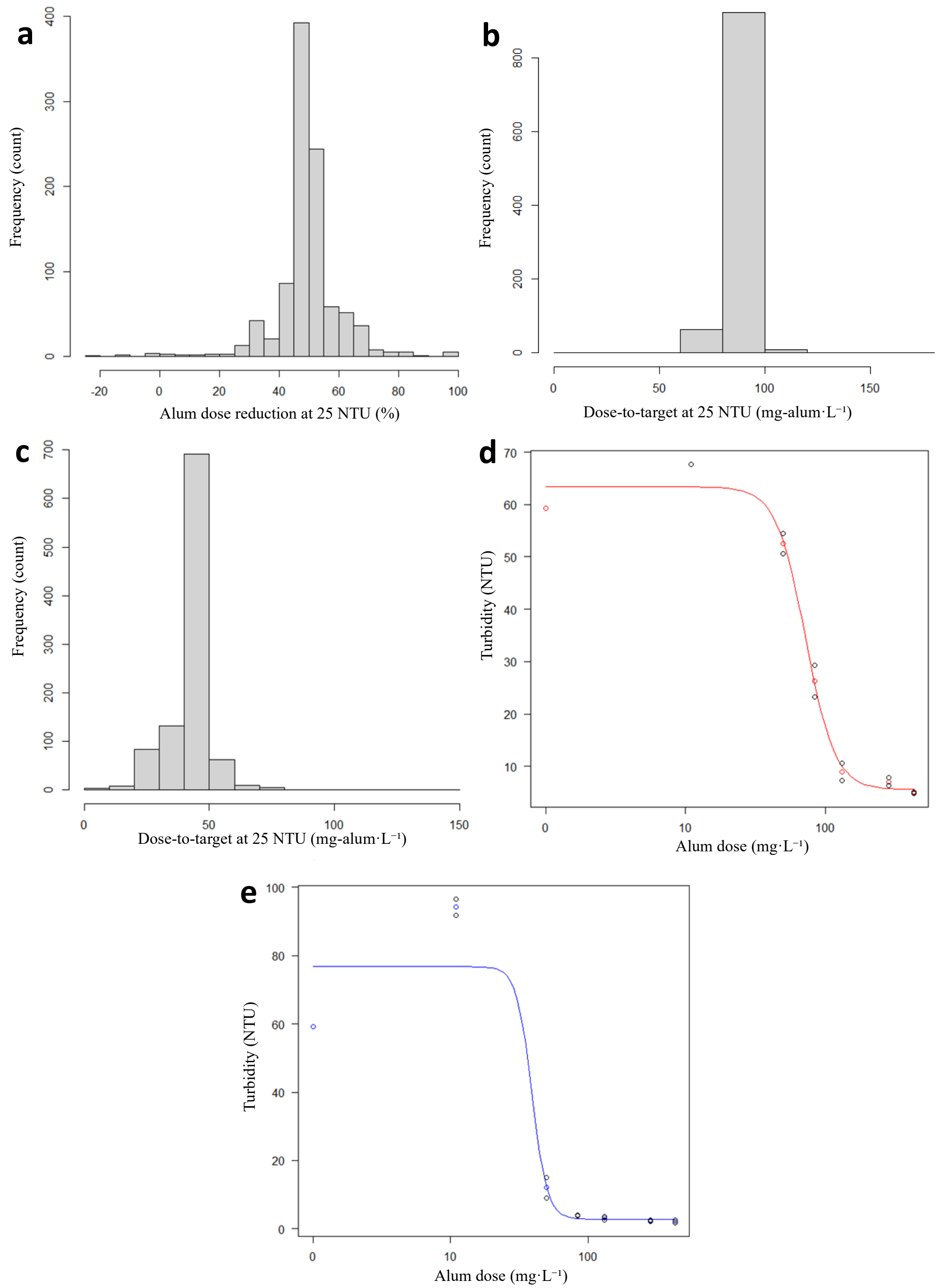


Fig. S1 I Bootstrap-supported modelling of alum dose reduction at the 25 NTU target for municipal wastewater. **a** Histogram of the cleaned bootstrap distribution of the estimated percentage reduction in alum demand at the 25 NTU threshold. **b** Bootstrap distribution of the model-derived alum dose required to reach 25 NTU under conventional (no fiber) conditions. **c** Bootstrap distribution of the model-derived alum dose required to reach 25 NTU under fiber-assisted conditions. **d** Four-parameter logistic fit to the turbidity–alum dose response for the no-fiber treatment; the curve represents the fitted model and points represent measured turbidity values. **e** Four-parameter logistic fit to the turbidity–alum dose response for the fiber-assisted treatment, with the same conventions as in **d**. The bootstrap procedure propagates experimental variability through model fitting to estimate the distribution of dose-to-target values and the corresponding reduction in alum demand.

Table S1 I Mean additional turbidity reduction achieved by screen pressing relative to 30-s and 3-min settling across the tested alum doses. Duplicate jars were first averaged for each alum dose, and percentage gains were then calculated relative to the corresponding settling turbidity before averaging across the six tested doses.

Matrix	Condition	Gain vs 30 sec	Gain vs 3 min
Wood industry wastewater	No fibers	15.1%	9.6%
Wood industry wastewater	With fibers	29.2%	4.7%
Dairy wastewater	No fibers	48.6%	23.8%
Dairy wastewater	With fibers	67.8%	28.3%
Municipal wastewater	No fibers	63.4%	13.7%
Municipal wastewater	With fibers	29.8%	7.2%
Agricultural wastewater	No fibers	39.6%	8.5%
Agricultural wastewater	With fibers	21.7%	4.9%

Table S2 I Summary of turbidity removal performance across various real wastewater matrices. Final turbidity values are reported for treatments conducted with and without fibers. Values correspond to duplicate experiments. The difference between fiber treatment and conventional treatment (without fibers) was statistically significant ($p < 0,05$).

					No fibers		With fibers		Turbidity Reduction with Fibers vs Conventional Treatment (%)
					Final Turbidity (NTU)		Final Turbidity (NTU)		
Water matrix	Alum ($mg \cdot L^{-1}$)	Polymer ($mg \cdot L^{-1}$)	Fiber ($mg \cdot L^{-1}$)	Initial turbidity NTU	Replicate 1	Replicate 2	Replicate 1	Replicate 2	
Landfill waste	250	2	200	54.4	5.44	4.81	3.97	3.95	23%
Landfill compost 1	250	2	200	30.8	13.8	11.3	2.03	4.24	75%
Landfill compost 2	750	2	200	32.3	5.8	5.9	4.92	3.57	27%
Cranberry wastewater	100	1	200	73.9	70	67.9	34.1	36	49%
Potato wash wastewater	29	1	200	4504	63.4	83.9	34.7	35.8	52%
Agricultural wastewater	50	1	200	53.9	52.6	52.67	17.27	16.17	68%
Dairy wastewater 1	428	1	200	178.3	8.2	10.8	8.3	9.6	6%
Dairy wastewater 2	100	1	200	103.3	43.8	46.3	26.4	25.5	42%
Wood Industry wastewater	284	1	200	59.3	50.9	48.8	21.7	20.9	57%
Concrete manufacturing wastewater	0	1	200	741	13.7	13.8	2.1	3	81%
Vessel sewage discharges	84	1	200	428.7	139	111.7	110.3	126.7	5%
Municipal wastewater 2	29	1	200	32.9	16.7	15.4	7.5	7.8	52%
Municipal wastewater 1	50	1	200	69.5	50.6	54.4	15	9.06	77%

Table S3 I Initial physicochemical characteristics of the real wastewater matrices tested Initial turbidity, pH, total organic carbon (TOC), and temperature of the real wastewater matrices used to evaluate the fiber-assisted coagulation–flocculation process. Values correspond to the initial conditions measured prior to treatment. N.A. indicates that the parameter was not available or not analyzed.

Water matrix	Initial turbidity (NTU)	pH	Total Organic Carbon ($mg \cdot L^{-1}$)	Temperature (°C)
Landfill waste	54.4	7.8	N.A.	22.0
Landfill compost 1	30.8	7.6	N.A.	21.6
Landfill compost 2	32.3	7.8	198.5	21.8
Cranberry wastewater	73.9	7.0	3865	21.7
Potato wash wastewater	4504	7.1	17.5	21.8
Agricultural wastewater	53.9	6.6	124.3	22.1
Dairy wastewater 1	178.3	7.8	85.0	21.7
Dairy wastewater 2	103.3	7.8	N.A.	21.9
Wood Industry wastewater	59.3	4.3	1263	22.1
Concrete manufacturing wastewater	741	11.8	N.A.	22.0
Vessel sewage discharges	428.7	7.2	N.A.	22.0
Municipal wastewater 2	32.9	8.1	34.2	22.1
Municipal wastewater 1	69.5	7.2	40.1	21.8

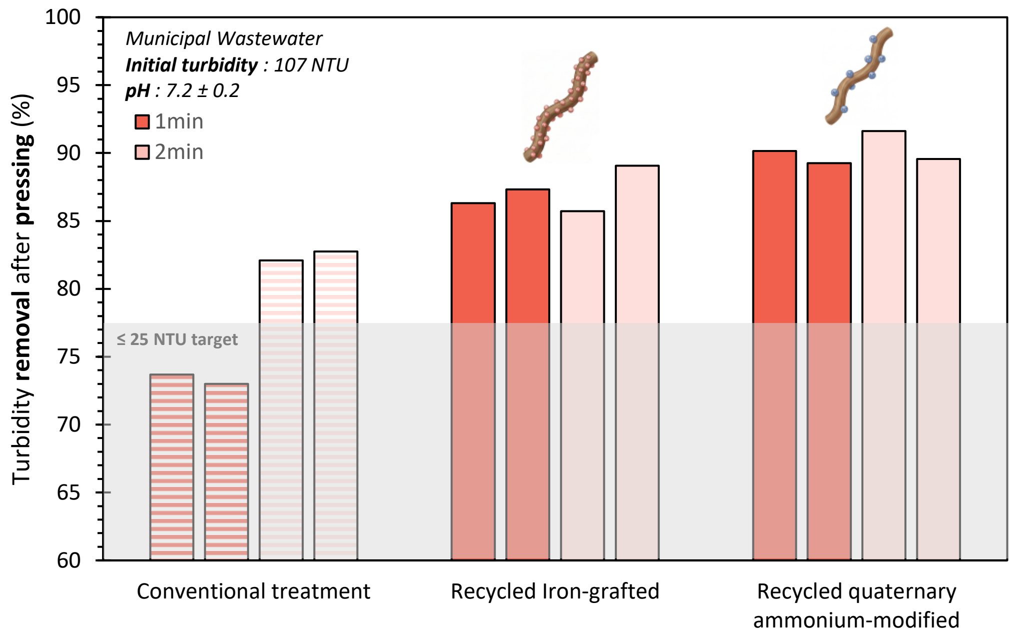
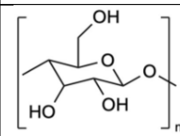
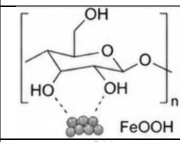
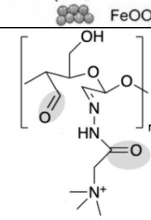
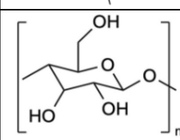
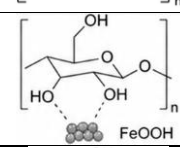
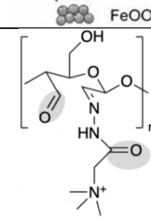


Fig. S2 I Sensitivity of fiber-assisted clarification to reduced flocculation time under reduced dosing. Turbidity removal in municipal wastewater (initial turbidity 107 NTU, pH 7.2 ± 0.2) after screening (200 µm) was evaluated by shortening the flocculation stage from the standard protocol (2 × 2 min) to a reduced-contact protocol (2 × 1 min), while maintaining the same coagulation conditions (suboptimal alum dose as defined in Fig. 2 and main text; aPAM and fiber dosing as in Fig. 5). Results are shown for the conventional treatment (no fibers) and two recycled functionalized fiber formulations (recycled iron-grafted and recycled quaternary ammonium–modified). The grey band indicates the minimum turbidity removal required to achieve the operational target of ≤25 NTU. Bars represent duplicate tests.

Table S4 I Physicochemical and structural characteristics of the cellulose-based fibers used for wastewater treatment. Summary of the cellulose-based fibers evaluated in this study, including fiber type, average length, zeta potential at pH 7, schematic surface structure, and raw material source. Iron-modified fibers are represented as cellulose fibers bearing surface-associated iron oxyhydroxide deposits, without implying covalent grafting. Quaternary ammonium-modified fibers are shown by their simplified functionalized cellulose structure.

Fibers type	**Average length (µm)**	**Zeta potential at pH 7 (mV)**	**Structure**	**Source**
Pristine	~810	-7.53		Eucalyptus hardwood cellulose
Pristine Iron-grafted	~680	-5.83		Eucalyptus hardwood cellulose
Pristine quaternary ammonium group-modified	~620	2.74		Eucalyptus hardwood cellulose
Recycled	~1680	-9.35		Recycled cardboard
Recycled Iron-grafted	~1540	-5.63		Recycled cardboard
Recycled quaternary ammonium group-modified	~1570	1.70		Recycled cardboard