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Optimizing an Integrated Biorefining Process for Birch Wood and Lignocellulosic Residues

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INTRODUCTION & AIM

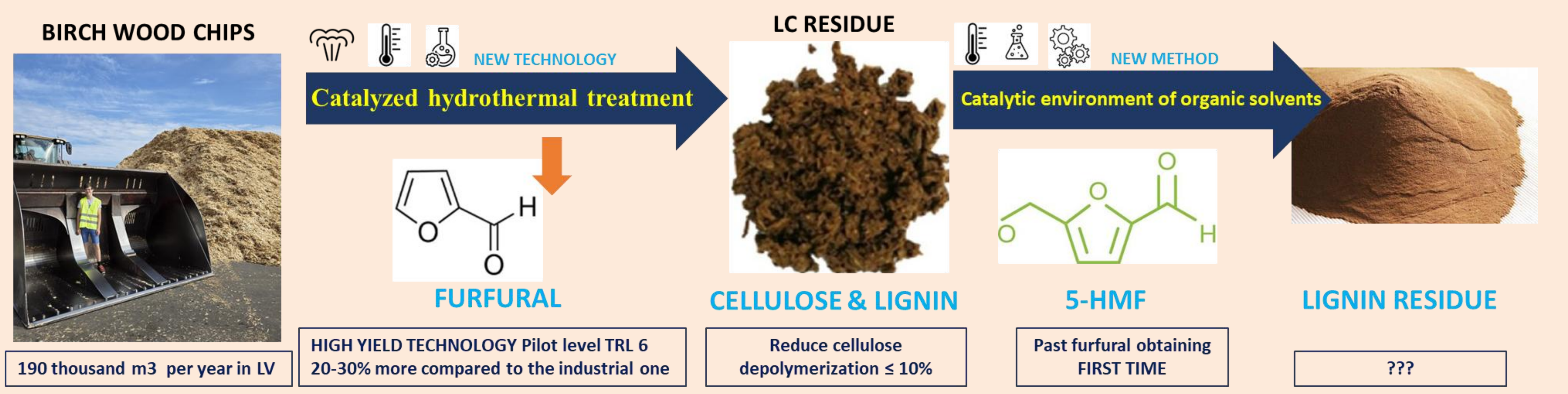
The birch wood industry is a key component of Latvia's forest-based economy [1] and presents significant potential for biorefinery innovations aligned with sustainability goals. This study proposes an integrated biorefining process for birch wood and lignocellulosic (LC) residues that enhances the preservation of cellulose while maximizing the yield of value-added chemical intermediates, specifically furfural and acetic acid.

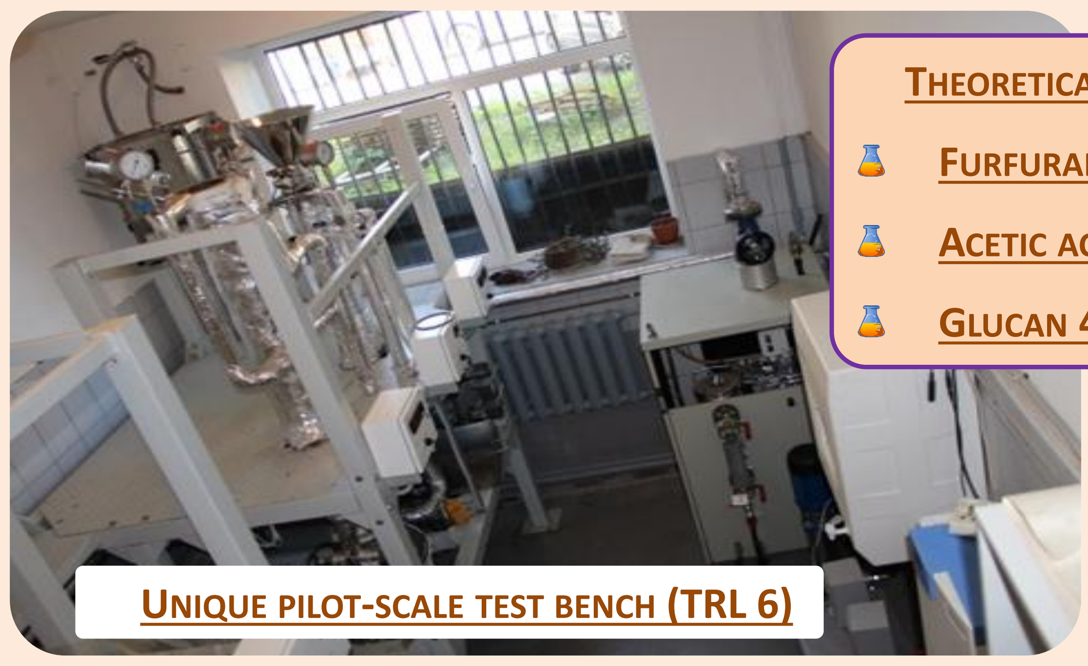
Traditional furfural production processes, which typically rely on sulfuric acid (H_2SO_4) catalysis, suffer from major drawbacks, including high cellulose degradation rates (40–50%) and the generation of environmentally hazardous sulfur-containing residues [2]. In response, a novel pretreatment method using phosphoric acid (H_3PO_4) as a catalyst was developed to enable selective furfural extraction with significantly reduced cellulose loss. The integration of this process with downstream production of 5-hydroxymethylfurfural (5-HMF) offers a promising biorefining platform.

METHOD

Birch wood chips (BWC) were used as the raw material. The chemical composition of the BWC and lignocellulosic residue was determined using standard methods: TAPPI 204 cm-07 for extractives, NREL/TP-510-42618 for carbohydrates, lignin and EN 14775 for ash. Optimization of the H_3PO_4-catalyzed BWC pretreatment was performed using a full factorial central composite design with response surface methodology (RSM; DesignExpert13). The studied factors were initial moisture content, temperature, catalyst concentration, catalyst amount (based on oven-dry mass), and steam flow rate. A total of 64 experiments were conducted using a unique bench-scale hydrolysis reactor. Factor levels were chosen based on preliminary results to cover the full range of practical conditions. The variable process parameters were as follows: temperature 155–175 °C, catalyst amount 2.5–5.5 wt.%, process duration 30–70 min, steam flow rate in the reaction zone 80–120 mL min^{-1}, and H_3PO_4 concentration 55%.

SHEME OF THE TECHNOLOGICAL PROCESS



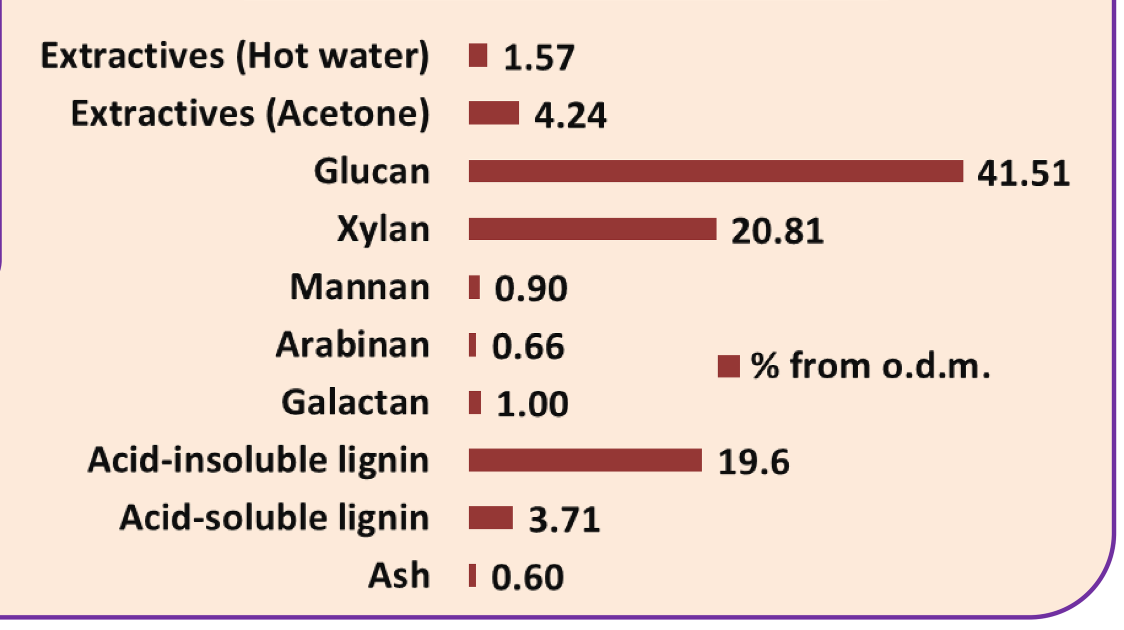


UNIQUE PILOT-SCALE TEST BENCH (TRL 6)

THEORETICAL YIELD OF:

- FURFURAL 15.40 % O.D.M.
- ACETIC ACID 6.48 % O.D.M.
- GLUCAN 41.51 % O.D.M.

CHEMICAL COMPOSITION OF BWC

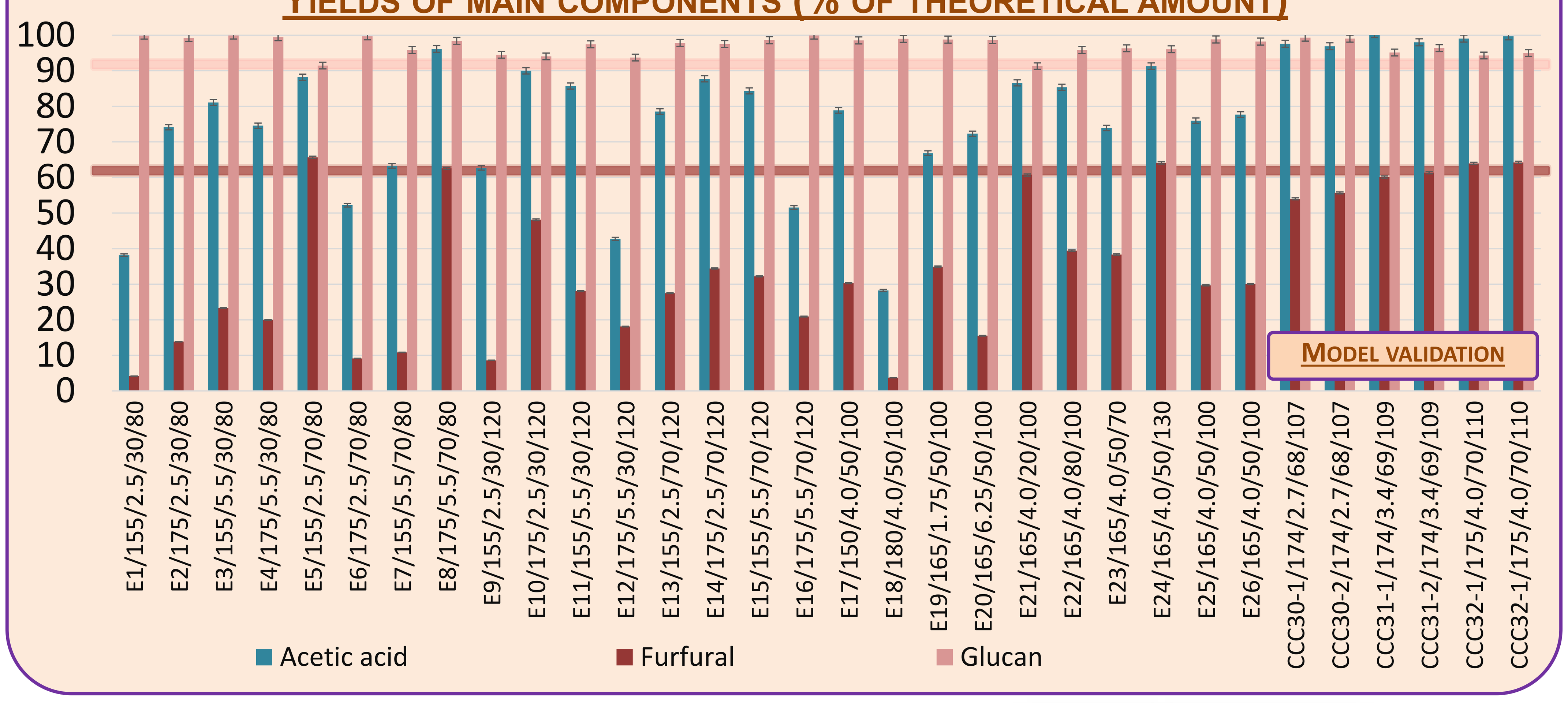


RESULTS & DISCUSSION

- The target furfural yield was set at 60% of the theoretical yield.
- Glucan loss was planned to be limited to ≤10% of the theoretical yield.
- Experimental investigations on the synthesis of 5-HMF from lignocellulosic residue are currently in progress.

MATHEMATICAL MODEL: **Furfural** = 608.39 – 4.013·Temp – 135.37·Catalyst amount – 2.09·Time – 7.0·Steam flow rate + 0.91·Temp·Catalyst amount + 0.016·Temp·Time + 0.044·Temp·Steam flow rate + 1.31·Catalyst amount·Steam flow rate – 0.78·(Catalyst amount)^2 – 0.0082·Temp·Catalyst amount·Steam flow rate.

YIELDS OF MAIN COMPONENTS (% OF THEORETICAL AMOUNT)



CONCLUSION

- BWC are a resource that is a by-product of plywood factories and is in large quantities.
- The chemical composition of BWC confirms the high potential for the biorefinery based processing pathways.
- The yields of the main products varied within narrow ranges, indicating stable process performance. The acetic acid yield ranged from 6.29% to 6.48% o.d.m. (97.57–100% of the theoretical maximum), the furfural yield from 8.75% to 10.41% o.d.m. (56.81–67.59% of the theoretical maximum), and the glucan yield from 38.84% to 40.92% o.d.m. (94.31–99.36% of the theoretical maximum).

REFERENCES

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2. Puke, M., Godina, D., Kirpluks, M., Brazdausks, P. Catalyzed Hydrothermal Pretreatment of Oat Husks for Integrated Production of Furfural and Lignocellulosic Residue. Polymers 5;16(5):707. 2024.

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