Department of Food, Agricultural and Biological Engineering

Techno-economic analysis of biobased novolac resin production

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INTRODUCTION

- Novolac resin is a phenolic resin used extensively in adhesives, abrasives, laminates, binding and insulating materials [1].
- Novolac resin was valued globally at approximately 6.5 billion USD in 2018 [1].
- Novolac resin is produced by reacting phenol and formaldehyde with an acid catalyst in an excess phenol environment [2].
- Phenol and formaldehyde used in novolac resin synthesis are exclusively obtained from petroleum refining [2].
- Alternative biobased source of phenol can be the phenolic compounds present in biooil produced via fast pyrolysis of lignocellulosic biomass [3].

OBJECTIVE

Evaluate the techno-economic feasibility of commercial biobased novolac resin production by partially substituting the petroleum-derived phenol with the water insoluble fraction of biooil that contains phenolic compounds.

METHODS

Modeling software: SuperPro Designer (Version 10)

Data sources: Experimental data, literature, databases

Production capacities: 25,000 and 100,000 metric tons per year (t/y) of novolac resin production based on existing resin production plants in the U.S. [4]

System boundary: From acquisition of pine chips to production of novolac resin (Fig. 2)

Phenol substitution ratio: 50% (by weight) of the total phenol required. Phenolic compounds comprise ~50% (by weight) of the water-insoluble fraction of biooil

Model inputs: Depicted in Fig.1

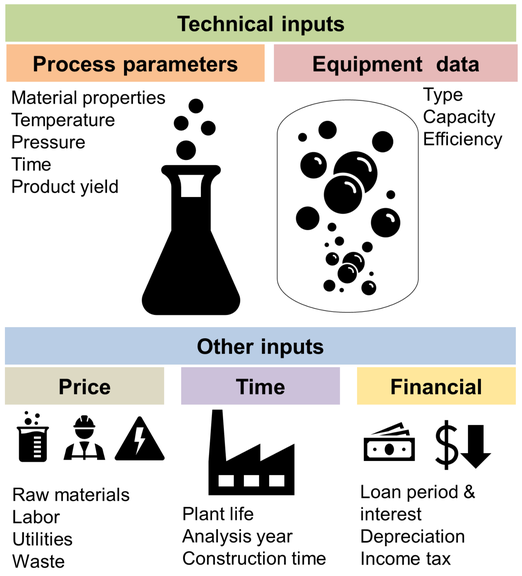


Fig. 1. Technical and other inputs required for the process model

RESULTS

Material balance

- Materials required for novolac resin production mainly consisted of pine chips, petroleum derived phenol and formaldehyde, hydrochloric acid, and water (Fig. 2).
- 45% of the biooil (by mass) was water-insoluble fraction and was used to substitute the phenol used in novolac resin synthesis.
- 90% of the phenol and 95% of the formaldehyde converted to novolac resin and the rest did not take part in the reaction.

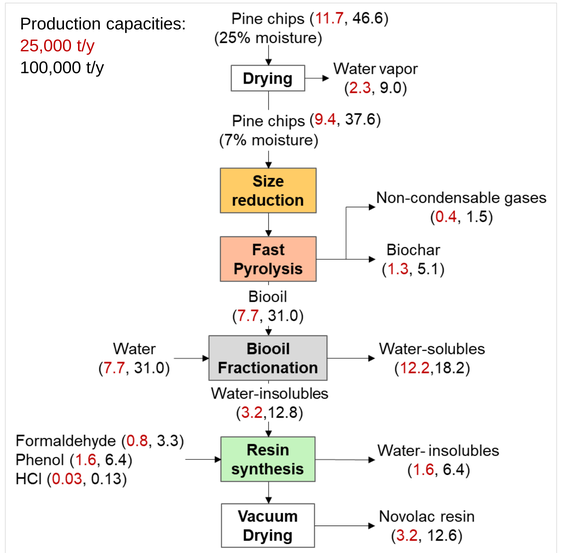


Fig. 2. Material flow (t/h) for the two production capacities

Utilities requirement

- Electricity was required for grinding during feedstock preparation and supplying heat for fast pyrolysis (Fig. 3).
- Steam was used as the heat transfer agent for drying the biomass in feedstock preparation, heating the resin synthesis reactor and vacuum drying the novolac resin during resin recovery.
- Chilled water was mostly required to quench the biooil after fast pyrolysis to separate biooil from the non-condensable gases.

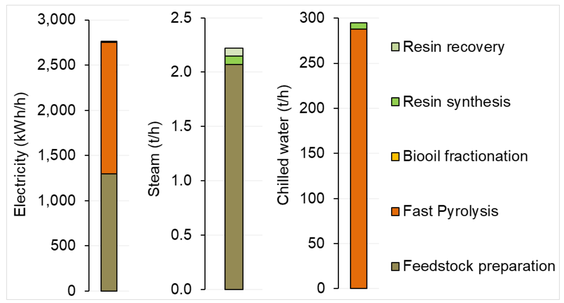


Fig. 3. Utilities requirements for 25,000 t/y novolac resin production (Note: Utilities requirement for 100,000 t/y production was proportional to the increase in capacity and is not shown here.)

Capital investment

- Capital investment for the 100,000 t/y capacity increased by 2-fold when the production increased by 4-fold due to economy of scale (Fig. 4).

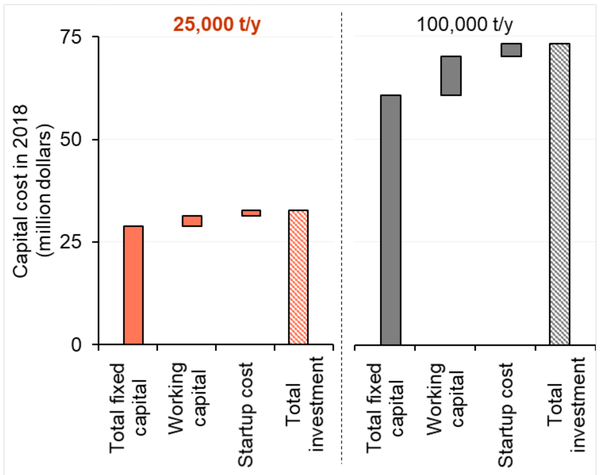


Fig. 4. Capital investment required for novolac resin production at two production capacities

(Note: Total fixed capital includes the cost of equipment purchase and installation along with building and facilities required for operating the plant. Working capital consists of funds at hand for operating the plant for up to 30 days, and start-up cost includes legal and registration fees, and other expenses incurred at the start of operation.)

Operating cost

- Novolac resin production cost decreased from $1,341/t at 25,000 t/y to $1,140/t at 100,000 t/y capacity because of economy of scale (Fig. 5).
- Raw materials cost contributed the most to the operating cost (54-64%) because it included the purchasing cost of phenol and biomass, which were used in large amounts, followed by utilities (21-24%), labor (3-10%) and facility dependent costs (8-13%).
- Facility dependent and labor costs were lower for 100,000 t/y compared to 25,000 t/y because higher quantity of novolac resin could be produced per unit equipment and labor hour.

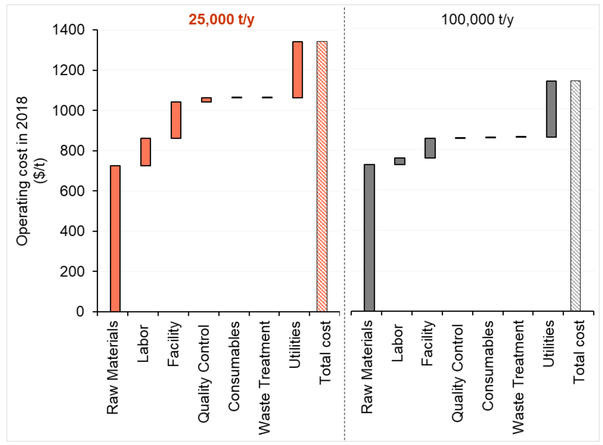


Fig. 5. Operating cost for novolac resin production at two production capacities

Sensitivity analysis

- Increasing the phenol substitution ratio to include more water-insoluble fraction reduced the resin yield and increased the novolac resin production cost (Fig. 6).
- The phenolic content of biooil used to substitute the phenol was one of the key parameters.

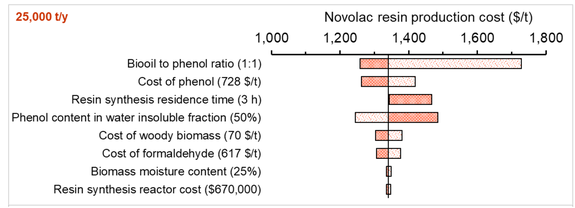


Fig. 6. Sensitivity analysis for 25,000 t/y with □ and ■ representing the increase and decrease, respectively, in the parameter values (Note: The impact of the different parameters had the same trend for 100,000 t/y production capacity and is not presented here.)

Financial analysis

Table 1. Financial analysis at 10% internal rate of return (IRR)

Production capacities (t/y)	25,000	100,000
Minimum selling price (MSP) ($/t)	1,468	1,203
Net present value (NPV) (million $)	9.8	21.1
Payback periods (years)	8.4	8.7

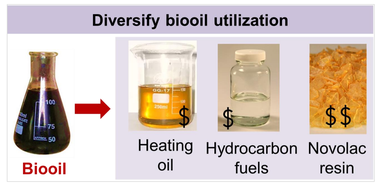
- Considering the average market price of novolac resin to be $2,066/t [5], payback periods for 25,000 and 100,000 t/y production capacities were 2.6 and 1.2 years, respectively.

CONCLUSIONS

- Production of biobased novolac resin is economically viable because the MSP of novolac resin obtained in this study is lower than the market price of novolac resin.
- The novolac resin production cost can be further reduced by sourcing low cost materials and increasing the production capacity of biooil and resin.

SIGNIFICANCE

One 100,000 t/y biobased novolac resin production plant alone can create up to **28 jobs**, earn up to **$121.5 million in revenue**, and pay up to **$3 million in taxes** every year.



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