



Techno-economic and life-cycle assessment of volatile oil extracted from *Aquilaria sinensis* using supercritical carbon dioxide

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ARTICLE INFO

Keywords:

Total capital investment
Operating cost
Profits
Environmental impact
Technology readiness level

ABSTRACT

Extracts of *Aquilaria sinensis* possess pharmacological activity that has been widely used in traditional medicines since ancient times. In this study, techno-economic assessment was conducted for extraction of volatile oil from abundant biomass (lignified ring) and resin of *A. sinensis* to evaluate their respective economic feasibility using supercritical carbon dioxide (SC-CO₂) extraction in Malaysia. The assessment revealed that for a production capacity of 5280 kg/y volatile oil, the total capital investment (TCI) was \$ 7.11 million from summation of fixed capital cost and working capital. In terms of operating expenditure (OPEX), the volatile oil extracted from resin and lignified ring of *A. sinensis* required \$ 81.96 million and \$ 52.39 million, respectively. The selling price of volatile oil from resin and lignified ring were estimated to be \$ 0.025 million/kg and \$ 0.0125 million/kg, respectively. Both volatile oil extracted from resin and lignified ring showed a positive net profit which indicated their profitability. In addition, a cradle-to-gate analysis of life-cycle assessment (LCA) was performed, whereby the extraction process contributed the highest impact towards the environment due to its high energy consumption. Nevertheless, this study estimated that the process might reduce the environmental impacts by approximately 90% when the technology readiness levels (TRLs) reach the level of 9–10. These findings are beneficial in providing preliminary insights in terms of economic and environmental aspects for volatile oil extraction using SC-CO₂ technology.

1. Introduction

The genus of *Aquilaria* species which is classified under plant family of *Thymelaeaceae* consists of resinous heartwood known as agarwood or gaharu. The term gaharu refers to the dark, dense and fragrant resinous wood located at the inner part of stem and branch of *Aquilaria* trees. It possesses pharmacological function and biological activity which has been used widely for medicines, perfumes and incenses. The stem of *Aquilaria* trees consists of resin that has unique balsamic notes and comprises of useful ingredients for perfumery which can be extracted as volatile oil [1]. For instance, many literatures have reported on pharmaceutical benefits of resin such as anti-inflammatory, anti-toxic, sedative, laxative and treatment in digestive, respiratory and nervous systems characteristics [2,3]. The lignified ring which is the outer layer of the resin comprises of a major portion from *Aquilaria* trees is

scrapped off in order to obtain resin that located at the inner part of the stem bark. It is usually disposed by the agriculturists after obtained the resin which indirectly contributed to the amount of wood waste. About 4.5 million t/y of wood waste is generated globally [4]. Thus, utilization of the lignified ring for the extraction of volatile oil with potential beneficial compounds has high novelty in generating wealth from biomass.

Owning to high market value of volatile oil, the selection of extraction method and well-designed process are necessary to obtain maximum yield of the volatile oil. The most common extraction techniques comprise of Soxhlet extraction and hydrodistillation. Soxhlet extraction requires organic solvent leading to disadvantages, such as cost of high purity, toxicity, and residue in the extracts which could potentially affect the environment and human health. At industrial scale, hydrodistillation extraction is usually applied to extract volatile

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<https://doi.org/10.1016/j.jcou.2020.01.002>

Received 27 February 2019; Received in revised form 23 December 2019; Accepted 3 January 2020

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