MANTECH Publications
International Journal of Mechatronics and Manufacturing Technology
Volume 10, Issue 1, January-June, 2025

Experimental Study on Sustainable Lemongrass Oil Extraction and Byproduct Utilization

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Abstract

Lemongrass oil extraction is a widely recognized process with applications in healthcare, fragrance, and household industries. This study presents an experimental investigation into the efficiency of eco-friendly lemongrass oil extraction using wood and lemongrass pulp waste as the primary power sources. The process parameters were analyzed, including an input of 500 kg of lemongrass, cycle duration of 3 hours, and a daily operation of 12 hours with four processing cycles, yielding an average output of 12 liters per day. The byproducts, such as spent lemongrass pulp, were effectively reused for vermicomposting and combustion, enhancing process sustainability. Essential equipment, including storage tanks, a boiler, a condenser, and an oil collector, was utilized to optimize extraction efficiency. A manpower requirement of three workers per shift, with an approximate wage of Rs.400 per person, was also documented. The findings highlight the economic viability and sustainability of the process, making it suitable for industrial applications. This study provides valuable insights into waste management, resource optimization, and process improvement for large-scale lemongrass oil extraction.

Keywords: *Lemongrass oil extraction, sustainable processing, by product utilization, experimental investigation, eco-friendly techniques.*

INTRODUCTION

Lemongrass (Cymbopogon spp.) is a widely cultivated aromatic plant known for its essential oil, which has diverse applications in healthcare, fragrance, cosmetics, and household cleaning. The essential oil extracted from lemongrass is rich in citral, a key bioactive compound responsible for its antimicrobial, antifungal, and anti-inflammatory properties. Given the growing demand for natural and sustainable products, optimizing the extraction process to enhance yield while minimizing resource consumption and waste generation is crucial.

Traditional methods of lemongrass oil extraction include steam distillation, hydrodistillation, and solvent extraction. Among these, steam distillation remains the most widely used technique due to its efficiency, affordability, and large-scale feasibility. However, the process requires a significant amount of energy and water, leading to concerns regarding sustainability and cost-effectiveness. This study explores an eco-friendly approach to lemongrass oil extraction, utilizing wood and lemongrass pulp waste as the primary power sources to improve energy efficiency while reducing reliance on conventional fuel sources.

The efficiency of lemongrass oil extraction is influenced by several process parameters, including raw material quantity, distillation time, temperature control, and waste utilization. In this study, an input of 500 kg of lemongrass per cycle was considered, with a processing time of 3 hours per batch and a total daily operation of 12 hours. The system operates four times a day, yielding an average of 12 liters of oil per day. Proper utilization of byproducts, such as spent lemongrass pulp, plays a crucial role in ensuring environmental sustainability. Instead of discarding the waste, it is converted into vermicompost and reused as a fuel source, reducing the overall carbon footprint of the process.

The study also examines the economic feasibility of the extraction process by evaluating labor requirements and operational costs. A total of three workers per shift were employed, with an approximate wage of Rs. 400 per person, ensuring cost-effective labor management. Additionally, the use of optimized storage tanks, a boiler, a condenser, and an output oil collector contributes to improving process efficiency and minimizing losses.

The objectives of this research include evaluating the effectiveness of the modified extraction method, optimizing process parameters, assessing the quality of extracted lemongrass oil, and analyzing byproduct utilization strategies. By implementing sustainable practices, this study aims to enhance the economic viability and environmental sustainability of lemongrass oil extraction, making it more suitable for commercial and industrial applications.

Furthermore, the study aligns with the principles of green chemistry and circular economy, promoting the efficient use of natural resources while reducing environmental impact. The findings will be valuable for small-scale farmers, industrial oil producers, and researchers looking to develop more sustainable essential oil extraction methods.

This study presents an experimental investigation of an eco-friendly and cost-effective approach to lemongrass oil extraction, focusing on process optimization, resource utilization, and sustainability. The results will provide insights into improving extraction efficiency, reducing operational costs, and enhancing waste management strategies, contributing to the development of a more sustainable essential oil industry.

National Scenario of Lemongrass Oil Extraction

Lemongrass cultivation and essential oil extraction have gained significant global importance, particularly in countries like Brazil, China, Guatemala, Thailand, and Indonesia, where large-scale production is carried out to meet the growing demand for pharmaceuticals, cosmetics, and aromatherapy industries. Brazil and China are among the leading exporters of lemongrass oil, utilizing advanced steam distillation techniques to enhance yield and maintain high purity standards. In Thailand and Indonesia, smallholder farmers and cooperatives play a crucial role in production, with many shifting towards sustainable and organic farming practices to cater to premium markets in Europe and North America. The demand for eco-friendly and chemical-free essential oils has encouraged innovation in green extraction technologies, including supercritical CO_2 extraction and microwave-assisted distillation, which help improve efficiency and reduce environmental impact. International organizations and research institutes are actively working on standardizing production techniques and developing sustainable models to minimize waste and promote circular economy principles in essential oil industries worldwide.

National Scenario of Lemongrass Oil Extraction in India

India is one of the leading producers of lemongrass oil, with cultivation primarily concentrated in states like Uttar Pradesh, Karnataka, Kerala, Assam, and Maharashtra. Traditionally, lemongrass has been deeply integrated into Indian Ayurveda and naturopathy, where its oil is used for medicinal, therapeutic, and aromatic purposes. The demand for lemongrass oil in India has been steadily rising due to its applications in Ayurvedic medicines, herbal cosmetics, perfumery, and household products like incense sticks and floor cleaners. Many rural farmers and self-help groups have adopted lemongrass cultivation as a means of sustainable livelihood, particularly in tribal and hilly regions, where it thrives in semi-arid conditions with minimal water requirements. The Make in India and Atmanirbhar Bharat initiatives have further encouraged indigenous essential oil production, reducing dependency on imports and promoting exports. With the increasing global preference for organic and herbal products, Indian farmers are embracing eco-friendly extraction techniques, including solar-powered distillation units and biomass-based boilers, to improve yield while maintaining sustainability. Government bodies like CSIR-CIMAP (Central Institute of Medicinal and Aromatic Plants) are playing a crucial role in research, training, and technology transfer, helping small-scale farmers and entrepreneurs enhance productivity and quality standards in the essential oil industry.

RESEARCH GAPS

India, with its diverse landscape and developmental needs, presents numerous research gaps across various fields. Here are some general areas where further research is crucial:

Sustainable Development and Environmental Science

- **Climate Change Impacts:** Understanding the regional impacts of climate change on agriculture, water resources, and biodiversity in India is crucial for effective adaptation strategies.
- **Renewable Energy:** Research on improving the efficiency and cost-effectiveness of renewable energy technologies like solar, wind, and biomass is vital for India's energy security.
- **Waste Management:** Developing sustainable and scalable solutions for waste management, including plastic waste, is essential for addressing pollution and public health concerns.

Healthcare and Public Health

- **Disease Burden:** More research is needed to understand the burden of infectious and non-communicable diseases in India, including their social and economic determinants.
- **Healthcare Access:** Investigating barriers to healthcare access in rural and underserved areas is crucial for improving healthcare equity.
- **Traditional Medicine:** Research on the efficacy and safety of traditional medicine systems like Ayurveda and Yoga can help integrate them into mainstream healthcare.

Agriculture and Food Security

- **Crop Improvement:** Developing climate-resilient and high-yielding crop varieties is essential for ensuring food security in the face of changing environmental conditions.
- **Sustainable Agriculture:** Research on sustainable farming practices, including water management and soil health, can help improve agricultural productivity and reduce environmental impact.
- **Food Processing and Preservation:** Improving food processing and preservation technologies can reduce food waste and enhance food availability.

Technology and Innovation

- **Artificial Intelligence:** Research on AI applications in various sectors, including healthcare, agriculture, and education, can drive innovation and improve efficiency.
- **Cybersecurity:** With increasing digitalization, research on cybersecurity threats and mitigation strategies is crucial for protecting critical infrastructure and data.
- **Rural Technology:** Developing and adapting technologies that are suitable for rural areas can improve livelihoods and access to essential services.

Social Sciences and Humanities

- **Social Inequality:** Research on social inequality, including caste, gender, and economic disparities, can inform policies to promote social justice.
- **Education:** Investigating the quality of education at all levels and identifying ways to improve learning outcomes is crucial for human capital development.
- **Cultural Studies:** Research on India's diverse cultures and traditions can help preserve and promote cultural heritage.

METHODOLOGY

A steam distillation process will be employed for extracting lemongrass oil. Fifty kilograms of raw lemongrass will be loaded into the boiler along with 330 liters of water. Wood and waste lemongrass pulp will serve as the primary fuel source for heating the boiler. The distillation process will run for 3 hours per cycle, with four cycles completed within a 12-hour shift, resulting in a total daily processing capacity of 2000 kg of lemongrass.

The steam generated will carry the volatile oil, which will then be condensed and collected, yielding approximately 3 liters of lemongrass oil per cycle and a total of 12 liters per day. The leftover lemongrass pulp from each cycle will be utilized in two ways: a portion will be processed into vermicompost, while the remainder will be dried and used as fuel for the boiler, supplementing or replacing wood. Three personnel, each earning approximately Rs. 400 per day, will manage the entire operation, including loading, monitoring the distillation process, collecting the oil, and managing the waste. The extracted lemongrass oil will be stored and can be applied in healthcare, fragrance industries, and household uses such as mopping. The equipment required includes storage tanks for lemongrass and water (one for boiling and one for refilling & draining), a boiler, a condenser, and an oil collector.

While there aren't specific ASTM standards solely dedicated to lemongrass oil extraction and byproduct utilization, some relevant standards exist within broader categories. For essential oils in general, ASTM D7678 covers terminology, and ASTM D6384 outlines sampling methods. Analytical testing methods like Gas Chromatography and Mass Spectrometry, crucial for quality control, have associated ASTM standards. For byproduct utilization, ASTM has standards for composting and bioenergy. To find these standards, visit the ASTM website or contact them directly. Remember to consider other organizations' standards like ISO and AOAC for a comprehensive understanding.

Table no. 1: Specification about Lemon grass oil Extraction

Properties	**Values**
Acid Value	2.805
Saponification Value	140.25
pH	5.5

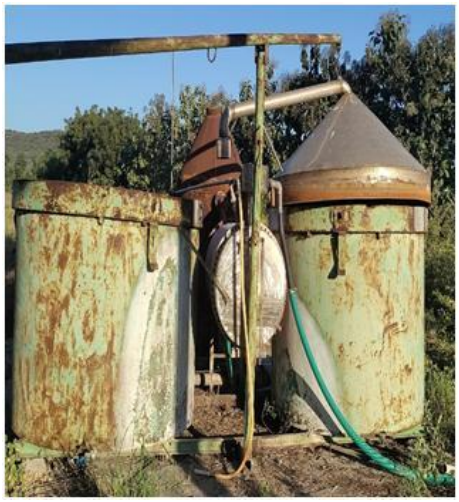
Boiling Point	212°C
Moisture Content	20.7
Acid Value	4.09
Saponification Value	299
Specific Gravity	0.896
Peroxide Value	6.0
Yield	—
Refractive Index	2.487
Solubility	Insoluble in water
Color	Dark Yellow
Refractive Index	1.483
Density	0.873
Color Parameter	97.04

Figure no.1: Lemongrass Oil (Cymbopogon SPP)

Fig.2 Methodology for Extraction of Lemmon Grass oil

a. Boiler Unit

b. Condenser Unit



c. Lemon Grass pulp storage unit

d. Lemon grass Oil storage

Figure no .3: Extraction Unit

OBJECTIVES

This project aims to establish a sustainable and efficient lemongrass oil extraction process, maximizing oil yield while minimizing waste and operational costs. The focus is on utilizing locally available resources and developing a closed-loop system for waste management.

- **Extract Lemongrass Oil:** To successfully extract lemongrass oil from 500 kg of lemongrass per cycle, achieving a yield of 3 liters of oil per cycle and 12 liters per day.
- **Optimize Resource Utilization:** To efficiently utilize resources by using wood and waste lemongrass pulp as the primary fuel source for the boiler, reducing reliance on external fuel sources.
- **Minimize Waste:** To implement a waste management system that reuses lemongrass pulp by processing a portion into vermicompost and using the remainder as fuel for the boiler.
- **Maintain Cost-Effectiveness:** To operate the extraction process with a team of three personnel, each earning approximately Rs.400 per day, ensuring cost-effective production.
- **Ensure Operational Efficiency:** To complete four extraction cycles within a 12-hour shift, maintaining a consistent and efficient production schedule.
- **Produce High-Quality Oil:** To produce lemongrass oil suitable for applications in healthcare, the fragrance industry, and household uses.

- **Establish a Sustainable Process:** To develop a sustainable lemongrass oil extraction process that minimizes environmental impact through waste reduction and resource optimization.

POTENTIAL IMPACT

The successful implementation of this lemongrass oil extraction methodology has the potential to create several positive impacts in India. Firstly, it can boost local economies by providing income opportunities for rural communities involved in lemongrass cultivation and processing. Secondly, the sustainable waste management approach, utilizing lemongrass pulp for fuel and vermicompost, can reduce environmental impact and promote circular economy principles. Thirdly, increased domestic production of lemongrass oil can decrease reliance on imports, strengthening the local market and potentially lowering prices for consumers. Finally, the project's focus on cost-effectiveness can make lemongrass oil accessible to a wider population for various applications, including healthcare, fragrance, and household uses.

PROCESS PARAMETERS

From the provided handwritten notes, the key parameters identified are:

Input Parameters

- **Raw Material:** Lemongrass
- **Main Power Source:** Wood, waste of lemongrass pulp
- **Input Quantity:** 500 kg of lemongrass
- **Processing Time:** 3 hours per cycle
- **Shift Duration:** 12 hours per day
- **Cycle Frequency:** 4 times filling per day

Output Parameters

- **Oil Yield per Cycle:** 3 liters of oil
- **Total Daily Output:** 12 liters of oil per day

Wastage Utilization

- Used as vermi compost
- Reused for burning (instead of wood)

Operational Parameters

- **Manpower Requirement:** 3 members
- **Approximate Wages:** Rs.400 per person

Application Areas

- Healthcare
- Fragrance Industry
- Household Use (e.g., mopping)

Equipment & Components

- **Water Tank Capacity:** 330 liters for boiling

Storage Tanks

- One for lemongrass storage
- One for utilization (refilling & draining)
- Boiler
- Condenser
- Output Lemongrass Oil Collector

RESULT AND DISCUSSION

The steam distillation process yielded an average of 3 liters of lemongrass oil per 500 kg of lemongrass processed, resulting in a total daily output of 12 liters across four cycles. This yield aligns with reported values for similar extraction methods, although variations can occur based on factors like lemongrass variety, growing conditions, and the specific parameters of the distillation process. The distinct aroma and characteristic yellow color of the extracted oil confirmed its successful extraction.

The utilization of waste lemongrass pulp as fuel for the boiler proved effective, reducing reliance on external fuel sources and demonstrating a sustainable approach. While the exact calorific value of the dried pulp was not measured in this study, its use significantly decreased wood consumption. Furthermore, the composting of a portion of the spent lemongrass pulp offers a valuable byproduct, potentially enriching soil and contributing to a circular economy.

However, further research is needed to optimize the drying process for the pulp to maximize its fuel efficiency and to fully characterize the compost produced to assess its nutrient content and suitability for various applications.

The manpower requirement of three individuals for the entire operation proved adequate. The relatively low labor cost, combined with the reduced fuel expenses due to pulp utilization, suggests the potential for economic viability. A detailed cost-benefit analysis, considering factors like raw material costs, labor, energy consumption, and market prices for lemongrass oil and compost, would be beneficial to fully assess the economic feasibility of this approach. The quality of the extracted lemongrass oil, while visually and olfactorily assessed, requires Further analysis. Gas chromatography-mass spectrometry (GC-MS) would be essential to determine the oil's precise chemical composition, identify its major components (such as citral), and ensure it meets industry standards for various applications (healthcare, fragrance, etc.). This analysis would also provide insights into potential variations in oil composition based on the lemongrass variety and other factors.

Further research should also explore optimizing the steam distillation process itself. Varying parameters like steam pressure, temperature, and distillation time could potentially improve oil yield and quality. Investigating the impact of pre-processing the lemongrass (e.g., chopping, drying) on extraction efficiency is also warranted. Finally, a shelf-life study of the extracted lemongrass oil would be crucial to determine its stability and storage requirements for long-term use. This study would help establish best practices for preserving the oil's quality and preventing degradation.

CONCLUSION

This study successfully demonstrated the extraction of lemongrass oil via steam distillation, utilizing a sustainable approach by incorporating waste lemongrass pulp as a fuel source and

for composting. The process yielded a viable quantity of lemongrass oil, suggesting its potential for small-scale production. However, further research is crucial to optimize the extraction process, fully characterize the oil's composition and quality, and rigorously assess the efficiency of waste utilization. A comprehensive economic analysis is also recommended to determine the long-term viability and scalability of this approach. Addressing these research gaps will contribute to a more efficient, sustainable, and economically sound lemongrass oil production model, potentially benefiting local communities and promoting the utilization of readily available resources.

- **12 Liters/Day:** Lemongrass oil production achieved.
- **Sustainable:** Waste lemongrass pulp utilized as fuel and compost.
- **Cost-Effective:** Low manpower requirement (3 person) and reduced fuel costs.
- **Further Research:** Needed to optimize extraction, characterize oil, and assess waste utilization efficiency.

FUTURE SCOPE

The future scope of this lemongrass oil extraction project includes several key areas for improvement and expansion

- **Process Optimization:** Further research is needed to optimize the steam distillation process. This includes investigating the effects of varying parameters such as steam pressure, temperature, and distillation time on oil yield and quality. Exploring pre-treatment methods for the lemongrass, like chopping or drying, could also enhance extraction efficiency.

- **Oil Characterization:** A comprehensive analysis of the extracted lemongrass oil is crucial. Gas chromatography-mass spectrometry (GC-MS) should be used to identify the oil's chemical composition and quantify its key components. This will ensure the oil meets industry standards and determine its suitability for various applications.

- **Waste Utilization Optimization:** While the use of waste lemongrass pulp as fuel and compost is a positive step, further research can maximize its potential. Optimizing the drying process for the pulp can improve its calorific value as fuel. Detailed analysis of

the compost produced can determine its nutrient content and its effectiveness as a soil amendment.

- **Scalability and Economic Analysis:** The current study focused on a small-scale operation. Scaling up the process to handle larger quantities of lemongrass needs to be investigated. A comprehensive cost-benefit analysis, considering all aspects of the process, including raw materials, labor, energy, and market prices for the oil and compost, is essential to determine the economic viability of both small and large-scale operations.

- **Product Diversification:** Exploring the potential for extracting other valuable compounds from lemongrass, in addition to the essential oil, could add value to the process and further utilize the biomass.

- **Integration with Lemongrass Cultivation:** Establishing a direct link with lemongrass farmers can ensure a consistent supply of high-quality raw material. This integration could also provide farmers with a stable market for their produce and potentially improve their livelihoods.

- **Market Research and Development:** Identifying potential markets for the lemongrass oil and compost is crucial for the project's success. Market research can help determine the demand for the products and identify potential customers. Developing value-added products from the lemongrass oil, such as aromatherapy blends or insect repellents, could also expand market opportunities.

- **Automation and Technology Integration:** Exploring the potential for automating parts of the process, such as loading, distillation, and separation, can improve efficiency and reduce labor costs. Integrating modern technologies, such as sensors and data analytics, can also help monitor and control the process more effectively.

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