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Design and Fabrication of a Small-Scale Dual-Purpose Essential Oil Extractor

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A B S T R A C T

This research paper presents the design and fabrication of a locally fabricated small-scale dual-purpose essential oil extractor, capable of performing both steam distillation and hydrodistillation. The design aims to address the growing global demand for essential oils, projected to reach $24.16 billion by 2032, driven by their diverse applications in aromatherapy, cosmetics, food preservation, and pharmaceuticals. The essential oil extractor was fabricated using stainless steel for its corrosion resistance, mechanical strength, and hygienic properties, ensuring the quality and durability of the extracted oils. The system was tested using fresh lemongrass, yielding 0.42% essential oil through steam distillation. The chemical composition of the oil was analyzed using GC-MS, identifying trans-Carveol (35.22%) and Geranial Citral (20.24%) as the major compounds. The high presence of these compounds suggests that the extracted oil has strong aromatic and flavoring properties, with potential uses in the fragrance, food, and cosmetic industries. This study demonstrates the feasibility of producing high-quality essential oils using a locally fabricated, cost-effective extractor suitable for domestic and small industrial applications.

Keywords: Essential oil, Lemongrass, Distillation, GCMS, Extractor.

1. Introduction

As of 2023, the global essential oil market was valued at approximately $10.59 billion and is projected to grow at a compound annual growth rate (CAGR) of 9.6% between 2024 and 2032, reaching an estimated $24.16 billion by 2032. This growth is driven by increasing consumer demand for natural and organic products, heightened health awareness, and expanding applications in aromatherapy, cosmetics, food and beverages, and pharmaceuticals (Expert Market Research, 2023).

Essential oils are plant-based volatile oils with strong aromatic components that are made up of different chemical compounds (Santos, et. al., 2021). For example, alcohols, hydrocarbons, phenols, aldehydes, esters and ketones are some of the major components of essential oil (Mkaddem 2024).

Recent studies highlight the growing popularity of plant-based medicines derived from essential oils due to concerns over synthetic chemicals and artificial preservatives (Mohamad, et. al., 2022). Essential oils are valued for their antimicrobial, antioxidant, and anti-inflammatory properties, making them a natural alternative in food safety and health applications (Kumar, et. al., 2020). For instance, oils like cinnamon, thyme, and rosemary have demonstrated effectiveness against pathogens and are used as natural preservatives in food, aligning with the increasing consumer demand for natural health products (Pezantes et. al., 2024). Numerous studies have demonstrated the efficiency of Essential Oils in low doses in the fight against bacterial pathogens even against multi-resistant bacteria (Iseppi, 2021). The effectiveness of these procedures has been attributed mainly to the presence of active phytochemicals or bioactive compounds in plants (Sharma, et. al., 2023). Given the scope of searching new antimicrobial agents (Ayu et al., 2022), antimicrobials derived from plant materials are often regarded as natural and safe compared to industrial chemicals.

The extraction of essential oils is a critical step in the utilization and valorization of medicinal plants, and various techniques have been employed to optimize the process. Conventional extraction methods, such as hydrodistillation and steam distillation, have been used extensively to obtain essential oils (Stéphane et al., 2022). These techniques rely on the application of heat and water or steam to extract the compounds of interest from the plant material. However, these methods can result in the degradation of thermolabile compounds and may not fully capture the complete aroma profile of the fresh raw material (Porto et al., 2009).

In recent years, there has been a growing interest in the development of more efficient and sustainable extraction techniques that can overcome the limitations of traditional methods. This research paper aims to present the design and fabrication of a small-scale (1L) dual-purpose essential oil extractor that can operate using both hydro and steam extraction modes, offering a versatile and potentially more gentle approach to essential oil extraction. (Roohinejad et al., 2017) (Porto et al., 2009).

2. Methodology

2.1. Material Selection

Material selection is a crucial step in the design and fabrication of any engineering project, as it directly impacts the performance, durability, safety, and cost-effectiveness of the final product. In the case of an essential oil extractor, the material must withstand varying temperatures, resist corrosion, and maintain the purity of the extracted oil. For the small-scale dual-purpose essential oil extractor, stainless steel was chosen as the primary material for fabrication. This chapter outlines the rationale behind the selection of stainless steel, its properties, and its suitability for essential oil extraction applications.

2.1.1. Criteria for Material Selection

Several key factors were considered in selecting the material for the essential oil extractor. Stainless steel was selected as the primary material for the fabrication of the essential oil extractor because it meets all the outlined criteria.

i. Corrosion Resistance: Essential oil extraction often involves exposure to water, steam, and organic compounds, all of which can accelerate the corrosion of certain materials. A material that resists corrosion is essential to prevent contamination of the oil and to prolong the life of the extractor.

ii. Mechanical Strength: The extractor must endure high pressures and temperatures during the extraction process. The chosen material should exhibit sufficient strength to avoid deformation or failure under these conditions.

iii. Thermal Conductivity: Efficient heat transfer is necessary for the extraction process, especially when heat or steam is used to extract essential oils. A material with good thermal conductivity ensures uniform heating, improving extraction efficiency.

iv. Hygienic Properties: Since the essential oil will be used in products such as perfumes, cosmetics, and pharmaceuticals, the material must maintain a high standard of hygiene and not react with or leach into the oil.

v. Fabricability: The material should be easy to work with in terms of cutting, welding, and shaping, allowing for the efficient production of the extractor.

vi. Cost: The material must be cost-effective, balancing performance with affordability, particularly for small-scale production.

2.2. Equipment Design and Specification

2.2.1. Extractor Design and Specification

Table 1 presents the design parameters and specifications of the small-scale dual-purpose essential oil extractor. The reactor is a batch type designed for steam distillation and hydrodistillation processes. The reactor will operate at an extraction temperature of 100°C under ambient pressure conditions (101.325 kPa). The essential oil extractor has a diameter of 0.300 m, a height of 0.500 m, and a total capacity of approximately 0.035 m^3 (35 L). Stainless steel, with a thermal conductivity of 45 W/mK, is used for the reactor's construction to ensure durability, resistance to corrosion, and efficient thermal management during the extraction process.

2.2.2. Condenser Design and Specification

The condenser is the unit to cool the outlet gases for the collection of the product (pyro oil). Table 2 shows that the condenser is a shell and tube condenser. The condenser is designed to have a duty of 12815.136 kJ/batch and a total heat transfer area of 0.2744 m^2.

Table 1 - Summary of Essential Oil Extractor Design Specifications

S/N	Item	Conditions/Assumptions
1	Ambient Temperature	25°C
2	Extraction Temperature	100°C (for steam distillation)
3	Height of Reactor/Extractor	500 mm (50 cm)
4	Height of Extractor Casing	530 mm (assuming 30 mm clearance for insulation)
5	Height of Heater	200 mm (for localized heating)
6	Thickness of Lagging (Insulation)	10 mm (thicker for better thermal insulation in essential oil extraction)
7	Volume of Reactor/Extractor	35,343 cm^3 (35L)

8	Area of the Reactor/Extractor	4712 cm^2
9	Thermal Conductivity of Stainless Steel	45 W/mK
10	Thermal Conductivity of Fiber Glass	0.04 W/mK (for insulation)
11	Thermal Conductivity of Aluminum Sheet	235 W/mK
12	Diameter of Reactor/Extractor	300 mm (30 cm)
13	Diameter of Aluminum Sheet	320 mm (for added insulation)

Table 2: Summary of Condenser Design

S/N	Parameter	Specification
1	Duty, kJ/Batch	12815.136
2	Shell Side	Cooling Water
3	Tube Side	Essential Oil from Lemongrass
4	Inlet Temperature (Tube/Shell)	100°C / 25°C
5	Outlet Temperature (Tube/Shell)	25°C / 45°C
6	Number of Tube Passes	1 (Helical shaped)
7	LMTD, K	55 K
8	Heat Transfer Area, m^2	0.3194 m^2
9	Tube Length, m	2 m
10	Tube OD, mm	11 mm
11	Tube ID, mm	10 mm
12	Number of Tubes	1
13	Tube Side Heat Transfer Coefficient, W/m^2K	99.973
14	Tube Side Pressure Drop, kPa	0.002
15	Shell Length, m	610 mm
16	Number of Baffles	2
17	Shell Side Fluid Velocity, m/sec	0.0032
18	Shell Side Fluid Density, kg/m^3	986
19	Shell Side Heat Transfer Coefficient, W/m^2K	150.706
20	Shell Side Pressure Drop, kPa	0.0001
21	Overall Heat Transfer Coefficient, W/m^2K	52.672
22	Shell Thickness, mm	3.5 mm
23	Safe Working Pressure, kPa	2923.009
24	Design Pressure, kPa	3215.309
25	Material of Construction	Carbon Steel

3. Working Drawings

3.1 Extractor (Distiller) and Condenser Working Drawings

The schematic diagram in Fig. 1a illustrates the essential oil extractor (distiller), which is a vertical cylindrical vessel supported by legs for stability. The diameter of the extractor is 350 mm. The total height of the extractor is 700 mm. This includes the main body of the extractor and the additional casing.

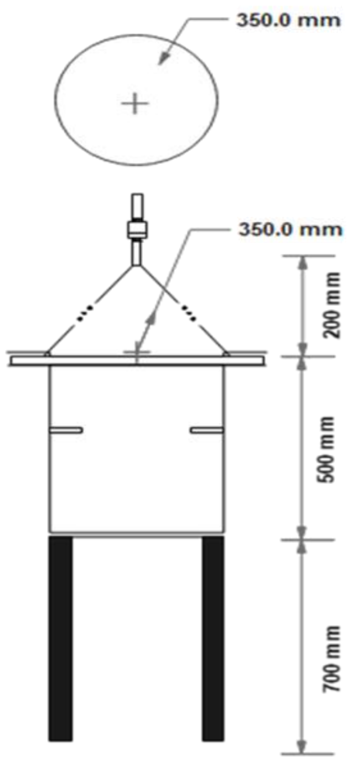

Fig. 1a:Schematic diagram of Extractor (Distillator)

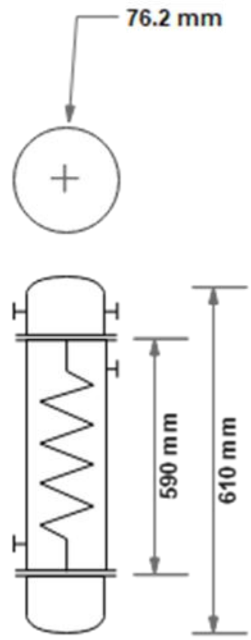

Fig. 1b: Schematic diagram of Condenser

Fig. 1b shows the 2D drawing for the condenser. The condenser is of the shell and tube with a single pass and helical tube. The height of the condenser is 610 mm and 76.2 mm in diameter.

3.2 Fabricated Essential Oil Distiller Unit

The extraction set up depicted in Fig.2 (3D model of the extractor) and Fig. 3 consists of two main parts, which are the distiller and the condensing unit. The cylindrical vessel is made of stainless steel, which is common in essential oil extraction due to its durability and resistance to corrosion. This extractor design is intended for the efficient distillation of essential oils, utilizing steam to vaporize and collect volatile compounds from plant material placed inside the reactor.

3.3 Extraction of Essential Oil and Essential Oil Yield

2kg of fresh lemon grass were charged into the oil extractor containing 20L of water. The electric heater was connected to start the heating. After about 1hr of boiling, steam and oil mixture began to drop out of the condenser. The oil was then separated from the warm water and measured using measuring cylinder. The oil was allowed to stand overnight followed by filtration to remove moisture and suspended impurities. The yield of the oil was calculated using the Equation (1):

$$\text{Yield}(\%) = \left(\frac{\text{Weight of extracted oil (g)}}{\text{Weight of lemongrass used (g)}}\right) \times 100 \quad (1)$$

The results showed that steam distillation of the essential yielded 0.42 %. The composition of the extracted oils was analyzed using GC-MS. This analysis provided detailed information on the chemical constituents of the oil, with a focus on citral content, which is the primary compound in lemongrass essential oil.

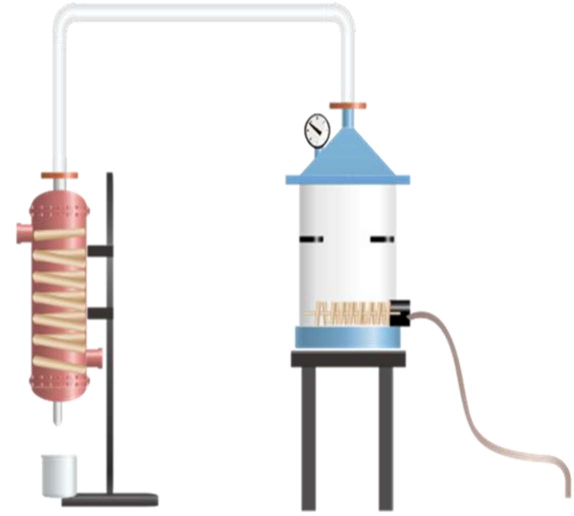

Fig. 2: 3D Model of Extractor (Distiller)

Fig. 3: Fabricated Extractor (Distiller)

4. Results and Discussion

Table 1 present the GCMS Analysis of Lemongrass Oil Extracted through Steam Distillation using the locally fabricated essential oil extractor.

Table 1 - GCMS Analysis of Lemongrass Oil Extracted through Steam Distillation

S/N	RT (min)	Compound Name	Area%	Description
1	9.413	Tricyclo[2.2.1.0(2,6)]heptane, 1,3,3-trimethyl-	3.65	Found in essential oils, used as a fragrance and flavor agent.
2	14.740	Isoneral	2.16	Citrus-like scent, used in perfumery and flavor applications.
3	15.230	3,6-Octadienal, 3,7-dimethyl- (Isogeranial)	2.78	Known for lemon-like scent, commonly used in fragrances.
4	16.927	trans-Carveol	35.22	Contributes a minty, herbal aroma; used in flavorings and perfumes.
5	17.341	2,6-Octadienal, 3,7-dimethyl- (Geranial Citral)	20.24	Lemon-scented, common in essential oils, widely used in perfumery.
6	17.731	1-Cyclohexene-1-carboxaldehyde, 2,6,6-trimethyl-	3.32	Often found in plant oils, used in fragrance and flavor industries.
7	20.275	Ethanol, 2-(3,3-dimethylcyclohexylidene)-, (Z)-	1.59	Used as an intermediate in chemical synthesis.
8	44.931	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.35	Found in fats and oils, used in cosmetics and pharmaceuticals.
9	45.046	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.80	Similar to the above; used as a lipid or surfactant in formulations.
10	45.074	Furan, 2-(diphenylamino)-4-(morpholinocarbonyl)-5-(p-nitrophenyl)-	0.20	Synthetic organic compound, used in research or material science.
11	45.398	Hexadecanoic acid, 2-[(1-oxotetradecyl)oxy]-1,3-propanediyl ester	2.56	Found in fats, used in emulsifiers and cosmetics.
12	45.467	10-Nitro-3,8,13,18-tetraethyl-2,7,12,17-	0.32	Possibly a synthetic compound,

		tetramethyl-21H,23H-porphine		could be used in dyes or research.
13	45.619	2-naphthalenecarboxamide, N,N-didecyl-1-hydroxy-	0.97	Used in industrial applications, possibly in dyes or coatings.
14	45.729	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.63	Common in skincare and cosmetic formulations as an emollient.
15	45.765	benzamide, N-[4-[[[4-(diethylamino)-2-methylphenyl]imino]methyl]-4,5-dihydro-5-oxo-1-phenyl-1H-pyrazol-3-yl]-	0.15	Synthetic organic compound, could be used in research.
16	45.865	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.66	Used in formulations for its emollient properties.
17	46.033	2-naphthalenecarboxamide, N,N-didecyl-1-hydroxy-	1.33	Industrial chemical, potential applications in materials.
18	46.077	10-Nitro-3,8,13,18-tetraethyl-2,7,12,17-tetramethyl-21H,23H-porphine	0.40	Synthetic compound, likely used in dye or material science research.
19	46.205	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.79	Similar to others; common in cosmetic and pharmaceutical formulations.
20	46.272	Furan, 2-(diphenylamino)-4-(morpholinocarbonyl)-5-(p-nitrophenyl)-	0.55	Synthetic compound, used in material research.
21	46.358	Octadecanoic acid, 3-[(1-oxohexadecyl)oxy]-2-[(1-oxotetradecyl)oxy]propyl ester	0.72	Another fatty acid ester, used in emollients and cosmetics.

The table shows that trans-Carveol and Geranial Citral are the dominant compounds, contributing over 55% of the essential oil composition. These compounds are commonly found in essential oils and are widely used in fragrances and flavorings. The presence of fatty acid esters like Octadecanoic acid derivatives indicates that the essential oil could have applications beyond aromatherapy, such as in cosmetics or pharmaceutical products.

5. Conclusion

5.1 Conclusion

The small-scale dual-purpose essential oil extractor designed and locally fabricated in this study successfully demonstrated the efficient extraction of essential oils, particularly from lemongrass. The use of stainless steel and the design of a versatile extraction system allowed for the production of high-quality oils, preserving the aromatic compounds effectively. The GC-MS analysis confirmed that the extracted oil was rich in key components like trans-Carveol and Geranial Citral, which are valuable in the fragrance and flavor industries. With a yield of 0.42%, the extractor proved to be a practical solution for small-scale operations. This work highlights the potential of accessible, locally fabricated equipment to meet the growing demand for natural essential oils in various industries, promoting both economic and sustainable practices. Future work could involve scaling the design for larger production capacities and exploring the optimization of extraction parameters to further enhance oil yields.

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