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Research Paper

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DESIGN AND PERFORMANCE ANALYSIS OF A COMPRESSOR-BASED PATCHOULI OIL DISTILLATION UNIT

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ABSTRACT. This study designs a compressor-based patchouli distillation unit and assesses its performance. The unit extracts patchouli essential oil from *Pogostemon cablin* Benth plants grown in Bone Bolango Regency. The distillation methods currently in use suffer from a lack of energy efficiency, long processing times, and poor oil quality. These result from uneven steam pressure and varying steam temperature. This study designs the aforementioned unit and tests its performance as a function of temperature, steam pressure, distillation time, oil yield, and total energy used. The system consists of a furnace, boiler, a pipeline for steam, a compressor, and a condenser. This system outperforms a unit with no compressor. The steam pressure and temperature from a compressor increase by 1.5 bar and 95°C to 2.5 bar and 110°C, respectively, and a reduction in distillation time occurs, from 10 to 6 hours. A further increase in oil yield occurs, from 2.5 to 3.8 kg. The quality and patchouli alcohol (PA) content of the oil improves, from 30 to 35%, respectively. Also, the oil yield improves, from 4.2 to 6.3%, and the distillation rate, energy efficiency, and specific energy consumption also improve. The compressor-based distillation unit is deemed to be the most productive and energy efficient of all studied systems.

INTRODUCTION

Patchouli oil (*Pogostemon cablin*) is internationally known and has high economic value (Dzulkarnain, 2020). Patchouli oil is an essential oil found in Indonesia. It is obtained by distilling the leaves, stems, and branches of the patchouli plant (*Pogostemon cablin* Benth) (Nurjanah, 2019). Essential oils contain aromatic compounds that are widely used in cosmetics, health, and food. Currently, the demand for aromatherapy products has increased significantly, indicating great potential for further development (Putri, 2020). Essential oils are complex mixtures of volatile organic compounds produced by certain aromatic plants and are characterized by distinctive aromas derived from components such as terpenes and phenyl propanoids (Sadgrove *et al*., 2022). Essential oils are volatile liquids obtained from plants.

Aromatic plant materials are extracted from various plant parts, such as roots, stems, leaves, and flowers, demonstrating significant potential for the development of bio-based industries. (Hamid and Silvarajoo, 2020). These substances serve as sources of high-value components in various sectors, including pharmaceuticals, cosmetics, and the food industry (Drinić and Zorica, 2020). In Indonesia, approximately nine to twelve types of essential oils are produced commercially. Among the many types of essential oils in Indonesia, only approximately 10–12 are commercially developed, with dominant commodities including patchouli, clove, cajuput, nutmeg, and citronella (Pramestari *et al*., 2024).

One of the main essential oil-producing plants with great economic potential in Indonesia is patchouli (*Pogostemon cablin* Benth), which is well known for its superior chemical composition and serves as a promising export commodity (Dewi and Ariani, 2023); (Setiawan, 2023); (Variyana, 2023); (Ginting, 2021). The patchouli plant contains active compounds that contribute to its therapeutic effectiveness across various industries, including sesquiterpenes with antioxidant, antimicrobial, and anti-inflammatory properties (Fatima, 2023); (Lee *et al.,* 2020).

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Gorontalo Province is one of the regions in Indonesia with a relatively large agricultural area, covering approximately 1,302,649 hectares, and has begun cultivating various crops. Patchouli cultivation, in terms of both cultivated area and production, increased from 2019 to 2021. However, a significant decline occurred between 2022 and 2023 (BPS Statistics Indonesia of Gorontalo Province, 2024). Therefore, the Gorontalo Provincial Government continues to promote the development of patchouli cultivation, which holds great potential in both the national and international markets (Simpulindo, 2025).

Bone Bolango Regency, located in Gorontalo Province, is one of the areas encouraged to develop patchouli cultivation, as the majority of its population works in the agricultural sector (BPS of Bone Bolango Regency, 2024). Since 2022, the provincial and regency governments of Gorontalo and Bone Bolango have continuously promoted the region as a priority area for patchouli development. This initiative has emerged alongside the growing interest of local farmers in shifting toward patchouli cultivation and the establishment of community-based industries that support patchouli cultivation and processing activities (Sanga, 2025).

Local farmers and small enterprises face challenges regarding the productivity and quality of patchouli oil. This involves the distillation efficiency. There is significant variation in the quality and quantity of patchouli oil produced, which primarily stems from differences in the handling of raw materials, methods and types of distillation technology, and operational parameters that are implemented. The traditional distillation methods that are usually employed, especially by small and medium enterprises, are inefficient and energy-consuming, and they are incapable of sustaining the optimal temperature and pressure state during distillation.

In a traditional steam distillation setup, steam is produced using a simple boiler, and the steam is sent directly into the reactor without controlling the flow or steam pressure. This induces problems in the system, leading to inconsistent heat that is not optimally distributed. In the system, the extraction is prolonged, and the quality and quantity of oil that is produced is low, and extraction of oil can last from 10 to 12 h. During inconsistent system operation, degradation of some of the thermally fragile bioactive principle constituents may occur. For example, the degradation of PA may take place, a quality determinant, and Destruction of PA impacts the selling price of the final product in the market.

To address these shortcomings, a compressor-based distillation system was developed to improve the performance and efficiency of the distillation process. When a compressor is added to the steam generation system, the system can produce pressurized saturated steam at a certain rate and pressure. This helps achieve a more uniform steam distribution throughout the reactor. Consequently, improved oil extraction efficiency, reduced processing time, and improved yield and chemical quality of the essential oil are anticipated.

The focus of the present study was to design, build, and assess a patchouli oil distillation unit that operates using a compressor. The other focus is to compare and study the thermal behavior, distillation efficiency, and energy consumption of the system. Compared to the existing system, the proposed compressor can maintain a higher pressure and temperature, and is more stable than the existing system.

The long-term development and application of energy-efficient distillation technologies in the patchouli oil industry will provide sustainable production and increase the competitiveness of the local patchouli oil industry in Bone Bolango Regency, Gorontalo Province.

MATERIALS AND METHODS

Research Framework

The purpose of this study was to develop and test a compressor-based patchouli plant oil distillation design. This study used a blend of experimental framework and distillation system performance analysis. This study encompasses three main phases.

1. The design and fabrication of the compressor-based distillation system,
2. The distillation system performance assessment,

An operational analysis of the unit was conducted to determine its efficiency and overall effectiveness. The flowchart in Figure 1 illustrates the stages of the compressor-based distillation system research process as follows.

1. Requirement Identification and Equipment Evaluation. This development phase starts with the identification of requirements and equipment evaluation. During this phase, data are gathered on the existing system's distillation deficiencies and the improvements required.
2. Design of the Distillation System. After requirement identification, the distillation system was designed, considering the diameter of the steam, pipes, and condenser. The aim is to achieve

equipment placement that promotes effectiveness and sustainability.

3. Selection of Materials and Components. This phase involves choosing the primary materials and components, such as the compressor, boiler, and condenser. The selection focuses on the durability of the components and their efficient and readily available materials.
4. Construction and Assembly of Distillation Unit. The distillation unit was constructed and assembled according to the design.
5. Initial System Testing. After assembling the unit, it was tested to determine whether it passed the no-leak test and whether all the components functioned as intended.
6. Calibration and Adjustment of the Pressure and Temperature Parameters. The main parameters, pressure and temperature, were adjusted to ensure that the system functioned as intended.
7. Performance Testing (Time, Temperature, Pressure, Oil Yield). Performance testing was conducted to determine the system's performance in terms of distillation time, temperature, pressure, and the amount of patchouli oil. In addition, a comparative analysis of oil and water was performed in relation to their required heating temperatures and volume ratios. The optimal ratio of oil to water was achieved based on the best distillation performance, which was determined by testing the oil yield as a function of the optimal heating temperature and pressure. The essential oil distillation unit operates as illustrated by the block diagram presented in Figure 2.

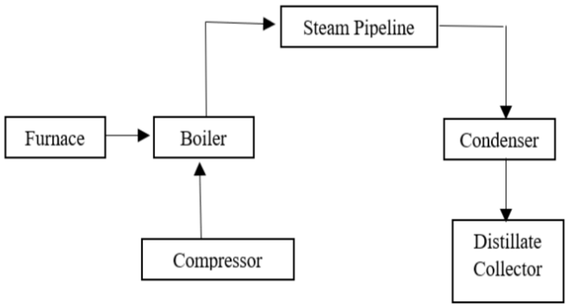

Figure 2. Block diagram of the compressor-based essential oil distillation unit for patchouli plants

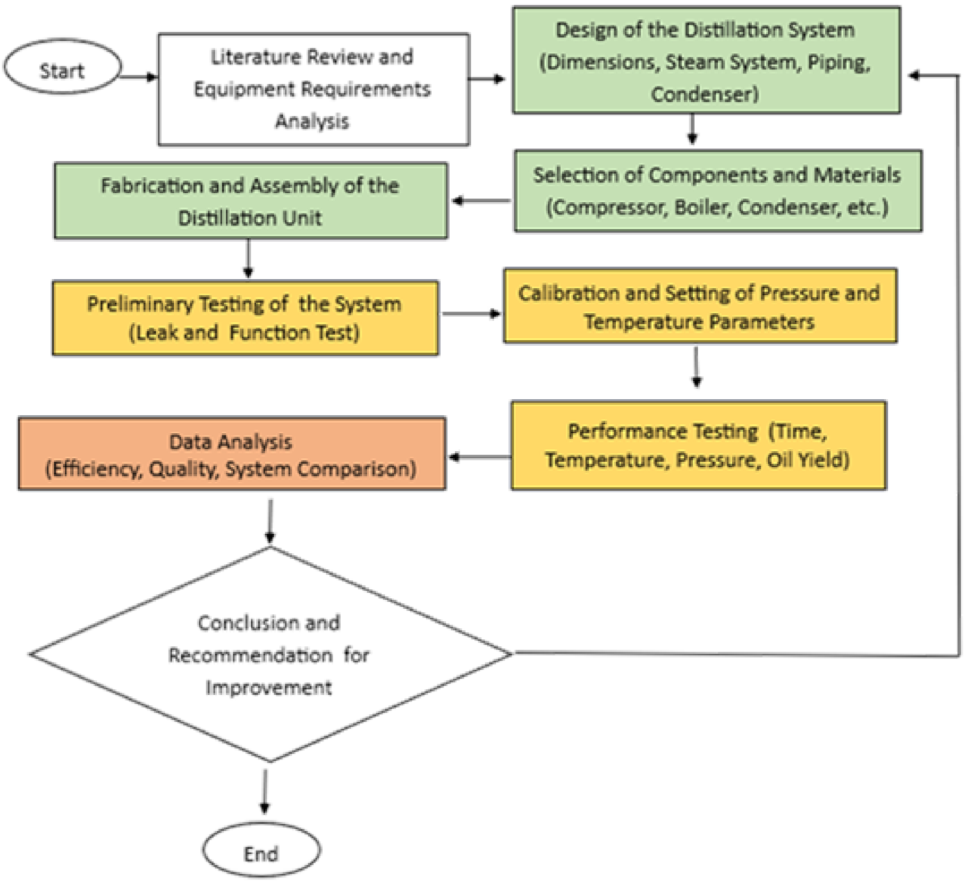

Figure 1. Research procedure flowchart

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a) Furnace
The purpose of the furnace is to provide heat to the water in the boiler to produce steam.
b) Boiler
The boiler is used as a container to heat the water, produce steam, and direct the steam to the distillation system through steam pipes. In this case, the distillation process is achieved with the aid of a compressor to control the steam pressure in the boiler.
c) Compressor
The role of the compressor is to increase the steam pressure in the boiler, so that the steam can pass through the pipes at an increased speed. This helps in better regulation of the pressure, thus channeling more steam for more efficient separation of essential oils from the plant materials.
d) Steam Pipeline
The steam pipe directs the hot steam from the boiler to the condenser. In this process, steam carries the volatile constituents (essential oils) of the substance to be distilled.
e) Condenser
The condenser takes the hot vapor, which contains essential oils, and cools it so that it can be converted to a liquid. The result of this process is a liquid composed of distilled water and essential oils.
f) Distillate Collector
The liquid is then collected in a container, where the essential oil and water separate owing to their different densities. The essential oil can then be used as is or subjected to further purification.
g) The experimental data will be analyzed to determine the efficiency of the system and oil quality. A comparison will also be made to assess how the developed system stacks up against other existing distillation systems and methods.
h) Conclusion and Improvement Recommendations. The results from the analysis will lead to the formulation of conclusions and improvement recommendations, which will serve as a guide prior to the system being approved for implementation.

Research Instruments

The following instruments were included for testing the distillation unit:

1. Measurement of operational parameters. This includes a digital thermometer to record optimal temperature levels for the greatest oil yield, a pressure sensor to ensure optimal pressure is achieved for the greatest oil extraction, a steam flow meter that measures the steam that enters the distillation chamber, and a digital scale to measure the weight of the patchouli raw materials before and after distillation.
2. Testing of distillation products. These instruments measure the quantity of essential oil produced through distillation.
3. Documenting and record keeping: The instruments record the distillation process, the changes that are visually observed at each stage of the process, and each stage of the testing process to provide reference points and evidence for the analysis of the results obtained from the experiments.

Experimental Procedure

The main steps of the experimental process were as follows: construction and assembly of the components, performance testing, and interpretation of the results.

1. Construction and Assembly of Distillation Unit. Improvement of the steam distillation unit for essential oil extraction from the point of view of steam pressure stability and energy saving is what this new unit is designed for. The steam distillation unit includes a boiler, condenser, separator, compressor, and connecting pipes. The compressor establishes a pressure differential and thus a stable steam pressure. The system design was based on a literature analysis, technical and operational requirements, and engineering calculations.
2. Phases of Data Gathering
    a. Finalizing Materials and Sample Normalization
    This step is imperative for achieving data uniformity and comparability. The raw patchouli leaves were subjected to primary chopping. The initial mass of this material was 60 kg.
    b. Instrument Preparation and Adjustment
    This step is performed to achieve the optimal operational state of the compressor-based distillation unit before the actual test is conducted. The regulated parameters were the system pressure (bar) and temperature of the condenser (°C).
    c. Research Population Identification
    The population of the present study encompassed all the operational parameters of the compressor-based patchouli oil distillation unit. The research samples are combinations of operational variables identified using a factorial experimental design. The variables analyzed included the compressor pressure,

temperature at the condenser, and duration of distillation, all of which were in two states, that is, conventional and the use of the compressor. In both scenarios, the raw material used was the same (60 kg).

d. Data Collection Procedure
   1) Loading patchouli leaves into the distillation unit
   2) Preheating the boiler until it reaches the boiling point
   3) Activating the compressor system applying pressure according to the predetermined variations to cool the condenser
   4) Running the distillation process
   5) Recording data at regular intervals (every 2 hours)
   6) Collecting oil samples
   7) Terminating the process after the distillation is completed

3. Performance Testing. For the purpose of each treatment, the performance of the distillation unit was assessed using 60 kg of dried patchouli leaves as raw material. The yield of the collected essential oil was measured, and the system energy consumption was monitored to calculate the thermal efficiency and specific energy consumption.
4. Data Collection and Analysis. The collected data pertaining to the temperature, pressure, and distillation time were analyzed to determine the performance characteristics of the system. The yield of patchouli oil was calculated based on the ratio of the mass of oil produced to the mass of the dry raw material.

Data Analysis Technique

1. Different measurements taken during distillation were finalized through data collection. Statistical and comparative analyses were performed to evaluate the data. The data were divided into two temporal segments for comparison. That is, they were analyzed (1) before and (2) after the compressor.
2. Temperature and Pressure. The data collected during distillation (temperature and pressure) were analyzed and assessed for their consistency and interrelation. Data were also collected using temperature probes. Time was a factor in data collection.
3. Essential Oil Yield. The yield was compared for the unit with the compressor and the one with traditional means of distillation. The yield was calculated using the following equation:
4.

$$Yield\ (\%) = \frac{Mass\ of\ oil\ produced\ (kg)}{Mass\ of\ raw\ material\ (kg)} x\ 100\ \%$$

RESULTS AND DISCUSSION

Experimental Data Processing

Design Overview for Compressor-Based Distillation Unit

This design describes an integrated distillation system for patchouli leaves that includes a boiler/reactor with an approximate capacity of ±400 kg. The primary steam generation system utilizes a 0.5 kW screw-type air compressor that provides pressurized air to the boiler, which is heated using a furnace-type combustion system.

All essential reactor and boiler components were built using galvanized steel to withstand high-temperature conditions and prevent corrosion. Stainless Steel 304 was used for the condenser because of its high efficiency in conducting heat and high chemical resistance against essential oil fume chemical reactions during oil condensation.

Once the compressor-based distillation unit is tested, there are several main steps in its operation.

1. Preliminary Steps
   a) Assess the location for safety and site readiness (Personal Protective Equipment (PPE), Ventilation, Fire Extinguishers, Fire Evacuation Routes).
   b) The distillation system components are as follows: Furnace, Boiler, Compressor, Condenser, Pipes and Collection, Safety Valve, and Instrumentation (Thermocoupler, Pressure Gauge, Flow Gauge, Digital Weighing Scale).
   c) Check the calibration of the instruments (Thermometers, Pressure Gauge, Flow Gauge, and Weighing Scale).
   d) The test material with the initial mass of the dried patchouli leaves should be prepared
2. Calibration of Equipment and Parameters
   a) The boiler was filled with water, and the leaves were placed in the distillation chamber.
   b) After the compressor and control valves were tested, the initial operating parameters of the distillation pressure
   c) Temperature should be entered to commence the operations of the system.
3. Leakage and Initial Function Test (Preliminary Test)

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a) The furnace and compressor are started and increased to reach nominal pressure and temperature.
b) If leakage is suspected in the connecting pipes and/or valves, check for leaks.
c) Determination of time to reach the specified operating conditions is made.

4. Operation and Data Collection (Main Experiment)
   a) The main experiment is the data collection at constant system conditions that support each other. Data collection was carried out every 15–30 min for the first time, then every 2 h for:
      - Temperature (boiler, steam entering the reactor, condenser)
      - Steam pressure (boiler)
      - Time
   b) The condensate was collected at regular intervals of every 2 h, and the oil was separated from the water to measure the volume.
   c) This process is repeated until the planned distillation time is reached.
5. Measurement of Energy Consumption and Efficiency
   a) The total electrical consumption for the compressor is recorded.
   b) The specific energy consumption is calculated and evaluated.
6. Product Quality Testing
   a) Oil samples are collected for analysis.
   b) Physical parameters, such as density, are measured.

The innovation of a pressurized steam system (steam compressor) in this study is that the use of a steam system allows for a more constant and even controlled steam supply to the reactor.

Food-grade stainless steel (SUS 304) was used to ensure safety and anti-corrosion features, as patchouli oil is slightly corrosive. The overall design of the distillation apparatus used in this study is shown in Figure 3, and the components and dimensions of the distillation apparatus are shown in Figure 4. The boiler has a patchouli leaf drying capacity of approximately ± 400 kg. The distillation unit was designed with a boiler diameter of 65 cm and a boiler length of 240 cm, whereas the evaporator was 160 cm long and 120 cm high.

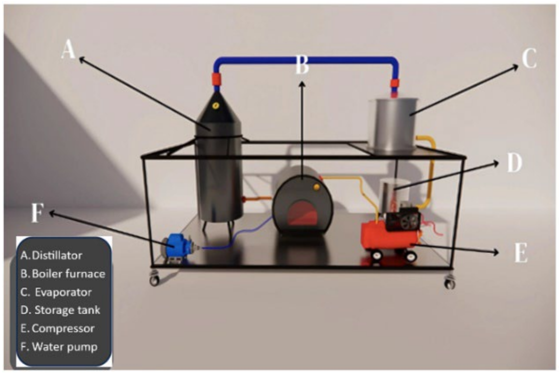

Figure 3. Compressor-based distillation system design

Functional Testing and Process Optimization

From the results of the functional testing, the controller system was able to maintain the reactor temperature at 110°C with a deviation of ±0.5°C. The ideal distillation time of patchouli raw material for maximum oil yield was 6 h.

Comparative Method

Product Quality Performance

This section compares the amount of oil produced and the energy used by the compressor and traditional distillation systems. It also seeks to determine the relationship between the use of a compressor and improved extraction performance while using a lesser amount of energy and improving the overall efficiency of the distillation process. Table 1 shows the data collected from various distillation processes.

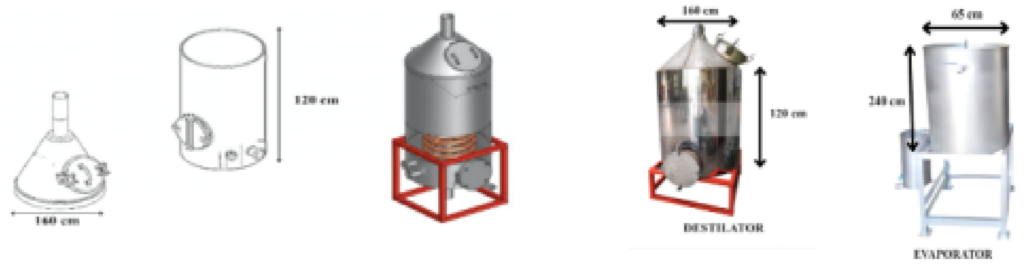

Figure 4. Components and dimensions of the apparatus compressor-based distillation

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Table 1. Comparison of operating parameters and distillation results before and after compressor use

Parameter	Before Using Compressor	Using Compressor
Initial mass of patchouli leaves (kg)	60	60
Compressor power (kW)	-	0.5
Boiler power (kW)	2	2
Pressure (bar)	1.5	2.5
Steam temperature (°C)	95	110
Distillation time (hour)	10	6
Oil produced (kg)	2.5	3.8
Patchouli Alcohol content (%)	30	35

Table 1 shows the data collected from the direct measurements of the patchouli oil distillation process. It also compares the conditions before and after the compressor was used. The time, produced oil, and distillate PA content, which indicates the distillate quality, were measured. The condensation pressure and boiling temperature of the steam were also measured.

From the data collected in the table, using a compressor means a clear change in working conditions. The system pressure changes, and the boiling steam temperature increases from 95 to 110 °C. The increase in system pressure indicates that the compressor-based system can generate and maintain equilibrium boiling conditions and, therefore, generate pressure in the system. This also indicates that the system can distill more quickly, which is, on the other hand, a lack of system pressure.

The distillation process takes 10 to 6 h. It also shows improved distillation and a better system efficiency. Faster distillation is attributed to better system operating conditions, improved distillation, and better system efficiency.

Another observation reflecting a positive benefit is seen in the number of oil produced, which ranges from 2.5 kg to 3.8 kg. This result indicates that the compressor not only reduces the time required for the process but also increases the yield. This means that more oil can be produced from raw materials in a short time.

The oil is also of higher quality. For example, the PA content showed a greater improvement from 30% to 35%. A hydrometer was used to determine the PA content. This is because changes in one of the physical properties can be used to infer the main oil content. This is one of the methods for measuring oil density. When patchouli alcohol was found to be greater, this implied that the compressor allowed the system to provide oil of greater quality in regard to its main active constituent.

The data summarized in the table suggest that, in terms of the system of production and the oil, the quantity, quality, and time of production of the oil improved significantly with the use of the compressor. This also suggests that for the processing of oil, the compressor system is more efficient than the other methods used for the distillation of oil.

The oil yield, distillation rate, and specific energy consumption were calculated using the first principles of energy and process engineering.

Oil Yield Calculation

The amount of raw material used in both experimental treatments was 60 kg each. In the first experiment, conducted without a compressor, the amount of oil obtained from the raw material was 2.5 kg. Based on the calculation of the oil yield using the percentage formula, the resulting oil yield was 4.2%. In the second experiment, the distillation process was assisted by a compressor. Using the same amount of raw material (60 kg), the amount of oil obtained increased to 3.8 kg.

$$Yield\ (\%) = \frac{Mass\ of\ oil\ produced\ (kg)}{Mass\ of\ raw\ material\ (kg)} x\ 100\ \%$$

<u>*Before using Compressor*</u>

$$\frac{2.5}{60}\ x\ 100\% = 4.2\%$$

<u>*Using Compressor*</u>

$$\frac{3.8}{60}\ x\ 100\% = 6.3\%$$

Based on the same calculation, the oil yield increased to 6.3%. The results of the two experiments demonstrate that the use of a compressor can improve the efficiency of oil extraction. The oil yield increased by 2.1% compared to the process without a compressor. This finding indicates that the compressor-assisted distillation system is more effective in recovering oil and is capable of producing a higher amount of oil from the same quantity of raw material than the conventional system.

Distillation Rate Calculation

The distillation rate represents the rate of patchouli oil production per unit time.

$$\text{Distillation Rate } = \frac{oil\ volume}{distillation\ time}$$

<u>Before Using Compressor</u>

Oil volume	:	2.5 kg		
Distillation time	:	10 hour	:	36000 Sekon
Distillation Rate	:	$\frac{2.5}{36000}$	:	$6.9\,x\,10^{-5}\ kg/s$

<u>Using Compressor</u>

Oil Volume	:	3 kg		
Distillation time	:	6 hour	:	21600 Sekon
Distillation Rate	:	$\frac{3}{21600}$	:	$1.3\,x\,10^{-4}\ kg/s$

Specific Energy Consumption (SEC) Calculation

SEC represents the amount of energy required to produce 1 kg of patchouli oil.

$$\text{SEC} = \frac{Energy\ total\ (joule)}{Oil\ mass\ (kg)}$$

Total energy is supplied by the boiler *(Before using compressor)*

$$E_{boiler=}\ P_{boiler}\ x\ t$$

Boiler power	:	2 kW		
Time	:	10 hour	:	36000 sekon

$$E = 1.5\ x\ 36000 = 72\ x\ 10^3\ joule$$

Oil mass : 2.5 kg

$$\text{SEC} = \frac{72\ x\ 10^3}{2.5} = 28.8\ x\ 10^3\ {}^{joule}/_{kg}$$

Compressor-based Energy System *(Using compressor)*

$$E_{compressor} = P_{compressor}\ x\ t$$

Boiler power	:	2 kW		
Compressor power	:	0.5 kW		
Time	:	6 hour	:	21600 sekon

$$E_{total} = (2 + 0.5) x\ 21600 = 54\ x\ 10^3\ joule$$

Oil mass : 3.8 kg

$$\text{SEC} = \frac{54\ x\ 10^3}{3.8} = 14.2\ x\ 10^3 \text{joule/kg}$$

The specific energy consumption of the compressor-based system was lower than that of the system without a compressor.

Table 2 presents the results of a comparative performance analysis of traditional distillation systems and those employing a compressor in the patchouli oil distillation process. The data presented in Table 2 illustrate notable distinctions in the average oil yield, distillation rate, and specific energy consumption of the two systems.

For average oil yield, the traditional distillation system achieved 4.2%, whereas the compressor-based system achieved 6.3%. This level of improvement indicates that the presence of a compressor in the system improves the extraction of oil from the raw material, suggesting that the compressor minimizes the loss of oil vapors during the condensation process of the oil vapors during the interim distillation process.

For the average distillation rate, 6.9×10^{-5} kg/s was recorded for the traditional system, whereas the compressor-based system achieved 1.3×10^{-4} kg/s. This shows that the compressor-assisted distillation system nearly doubles the performance of the traditional distillation system.

This is the result of an improvement in the performance of the condenser, which improves the rate of condensation of the oil vapor to liquid, and the distillation system achieves a nearly constant outflow of the distillate.

For the specific energy consumption, the traditional system requires 28.8×10^3 J/kg, whereas the compressor-based system requires 14.2×10^3 J/kg. This implies that the compressor-based system is relatively more energy-efficient in that, despite the higher distillation rate, the system consumes less energy. The compressor-based system achieves a higher distillation rate and is more energy-efficient because the system consumes less energy to achieve a higher distillation output. This is likely to be as a result of a relatively shorter distillation process, as well as the relatively reduced heat loss during the process.

In general, the results show that the conventional system is inferior in terms of yield, processing speed, and energy efficiency compared to the compressor-based distillation system.

Table 2. Comparison of yield, distillation rate, and energy consumption before and after compressor use

Performance Parameters	Before using compressor	Using Compressor
Average oil yield (%)	4.2	6.3
Distillation rate (kg/s)	$6.9\ x\ 10^{-5}$	$1.3\ x\ 10^{-4}$
Specific Energy Consumption (joule/kg)	$28.8\ x\ 10^3$	$14.2\ x\ 10^3$

Thus, integrating compressor technology into distillation systems for patchouli oil results in better energy and productivity outcomes in the essential oil industry. For small-to-medium scale oil processing companies, especially those processing patchouli oil in the region of Bone Bolango, the compressor-based distillation system is feasible and both technically and economically encouraged.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results from the compressor-based patchouli oil distillation unit indicate the following:

1. The compressor-based distillation setup yielded better results than the standard setup because of the enhanced operating conditions. With the setup, the steam pressure increased from 1.5 to 2.5 bar, while the steam temperature improved from 95 to 110°C, thus improving the efficiency of the evaporation and subsequent condensation of the essential oil.
2. An improvement in the process efficiency was observed when the distillation duration was reduced from 10 h to 6 h. The new technology improved the oil yield from 2.5 kg to 3.8 kg, thus producing 2.5 kg more essential oil. With the new setup, the oil produced was of better quality, as indicated by the increase in patchouli alcohol (PA) from 30% to 35%, as measured by a hydrometer.
3. An oil yield improvement from 4.2% to 6.3% was observed, with nearly a 100% improvement in the distillation rate, coupled with a major reduction in the specific energy consumption. This compressor-based system was not only more productive but also more energy efficient.
4. The patchouli oil compressor system distillation integration yielded a better improvement in the overall production in terms of energy efficiency, production quantity, and quality of goods.

Recommendations

Future research should evaluate the effect of variations in compressor capacity on improving oil yield, energy efficiency, and distillation time to determine the optimal system configuration. In addition, to improve data accuracy, the development of a monitoring system based on digital sensors and the Internet of Things (IoT) is needed to monitor operating parameters in real time, such as pressure, temperature, and steam flow rate, thereby ensuring a more stable, efficient, and sustainable distillation process.

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