Analytical study vessel design of the portable patchouli oil steam boiler based on vacuum technology

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Abstract. Aceh geography is suitable for growing pogostemon cablin with high quality. Traditionally, patchouli oil extraction is carried out using distillation techniques. However, the results are unsatisfactory due to impurities substances presence in the boilers. High energy wastage is common in the traditional distillation technique process due to improper vessel design. The study aims to design and rate the vessel of portable distillate patchouli oil based on vacuum technology. The simplified vessel design and proposed vessel design were then tasted to find a proper design with respect to ASME boilers and pressure-related VIII Vessel Code. However, internal and external pressure employed in both design and operation, given that the simplified model is 56.91 MPa and Sa is 116 MPa. The vessel design is yield to proposed model stress (Kmean) ≤ Sa Kmean is 86.13 MPa and Sa is 116 MPa. The analytical calculation and simulation results show that von-mises stress is less than the allowable stress material.

1. Introduction
Aceh is a competitive producer of patchouli oil (pogostemon cablin, benth) containing patchouli alcohol (pa) with a 30% base quality standard [1]. Ministry of law and defense in the republic of Indonesia set up rules protecting Aceh patchouli plantation geographic region specifically with IDG 00000021 certificate [2]. In the world’s market, patchouli oil use is in fragrance products. It is also popular as a raw material for a number of products such as antiseptics, aromatherapy, cosmetics, and a fixative to bind other essential oils. Its flavor is difficult to substitute with other synthetic compounds.

Traditionally, patchouli oil is extracted from the leaves, stem, and branches using the distillation techniques [3,4]. Currently, this technique is not optimally producing patchouli oil with high quality in view of the fact that the oil contains unwanted chemical substances such as Ferrum (Fe) and Cuprum (Cu). The impurities trigger the patchouli oil color, turning it dark causing PA level lower Indonesia National Standard (SNI). At koperasi KINA Aceh Jaya, Indonesia, most patchouli farmer groups apply the used-oil drum as a vessel that is a corrosive material and firewood as a source of energy to distillate patchouli oil. Distilled steam is only produced by a single unit of boiler from two units of the available. Steam is not properly distributed around of vessel due to lack of optimum design vessel. Extracting dry pogostemon cablin takes approximately 7-8 hours, which is not worth compared to end results. Therefore, the design and material type of a distillation boiler significantly contribute to low grade and economic values of patchouli oil. The objective of this study is to design and evaluate the vessel type of portable distilled patchouli oil.
2. Material and methods

2.1. Material
The patchouli leaves (pogostemon cablin, benth) used in this work, comes from Aceh Jaya, Aceh, Indonesia. The raw materials kept at room temperature in the storage facility. Experimental work carried out using distilled water.

2.2. Methods
The proposed design model of portable distilled patchouli oil vessel using vacuum technology refers to ASME VIII Boiler and Pressure Vessel Code requirement [5,6], as shown in Figure 1.

![3D model of portable distilled patchouli oil unit](image)

Figure 1. 3D model of portable distilled patchouli oil unit

To enhance the patchouli oil distilling process, six main issues were considered (as shown in Figure 2):

a) Energy source: Electric source was replaced with firewood to avoid contamination from hydrocarbon substances, and it was manageable by a control system.

b) Reliability, the system is a redesign to improve the performance of the current vessel and attain less negative impact on the environment (green technique) with a reasonable cost of production.

c) Purification water: The level of purification water surrounding the farm area was not appropriate enough to be used as raw water because it steamed in the distillation process. The purification water system was installed to provide water supply.

d) The pressure vessel was to consider design under the high-temperature condition and different energy sources in order to perform efficiency of energy and water utilities.

e) Condenser: Condenser pipe length was designed longer than the current system. Quick coolant system (QCS), with a cooling material temperature near 00C, was used to maximize the steam condensing process to condensate water.

f) Frame structure as the main board of the system was designed for an integrated portable system that was easy to carry and move from one place to another.

Pressure vessel construction design played a key role in the system. Its main parts consist of shell and head (see Fig.3). In the distillation process, the vessel worked under a certain number of pressure conditions. Since stress and strain worked in the vessel, a calculation was necessary to maintain life span and vessel reliability.
Figure 2. A schematic diagram of the portable distilled patchouli oil vessel using vacuum technology

Figure 3. Vessel design and its main parts

In the shell section, the circumferential and latitudinal stress are in common existence and vice versa for head section meridional and latitudinal presented. This type of stress does not exist for the cone and conical shape of the vessel head. Stress works in shell calculated refer to relation in \( P_{ht} \) pressure design (psi), \( r_m \) mean radium (in), \( t_m \). The thickness required of shell, head, or cone (in) is presented in the Eq. 1:
longitudinal stress

\[ \sigma_{\phi} = \frac{Pr_in}{0.2t} \]  

(1)

circumferential stress

\[ \sigma_{\theta} = \frac{Pr_in}{t} \]  

(2)

for cone and conical shape, working stress depends on the angle between two of cone diameters (\(a\)):

longitudinal stress

\[ \sigma_x = \frac{Pr_in}{2 + \cos a} \]  

(3)

circumferential stress

\[ \sigma_{\theta} = \frac{Pr_in}{r \cos a} \]  

(4)

Distortion, stress equivalency or von-misses stress is reference stress that is commonly used to analyze and predict design failure. \(\sigma_{vm}\) Von-misses stress (psi) refers to \(\sigma_x\) longitudinal stress (psi), \(\sigma_{\theta}\) circumferential stress (psi) and direction of welding (hoop), as present in Eq. 6:

\[ \sigma_{vm} = \sqrt{\frac{(\sigma_x - \sigma_{\theta})^2 + (\sigma_{\theta} - \sigma_t)^2 + (\sigma_t - \sigma_x)^2}{2}} \]  

(5)

In this study, a 3D model of vessel design and finite element analyses were performed on a desktop computer (IntelCore™ i7-4710HQ, 3.5 GHz processor, RAM 16 GB, Windows 10 operating system). The capacity of the vessel design proposed was 30 Kg and 20 litters of distilled water as suggested by farmers group KINA Aceh Jaya, Aceh, Indonesia. Detailed design of vessel parameters is shown in Table 1 and the material used in the computational simulation (stainless steel, thickness 1/8 in) is shown in Table 2.

| Vessel design condition and operation parameters |
|-----------------------------------------------|
| Initial pressure (operation) (Psi) | Initial pressure (vacuum) (Psi) | Operation pressure (Psi) | Designed pressure (Psi) | Temp. (F) | Designed temp. (F) | Heater temp. (F) |
|-----------------------------------------------|
| 0 | 4351132 | 4351132 | 7251887 | 176 | 572 | 392 |

| The material of vessel design |
|--------------------------------|
| Stainless Steel | Composition | Tensile (Psi) | Yield (Psi) | Min. Temp. (F) | Max. Temp. (F) | Corrosion factor | Welding factor |
|--------------------------------|
| UNS. No. S30400 | 18Cr-8Ni | 74984.51 | 30022.81 | -427 | 1500.8 | 0.03 | 0.6 |
3. Result and discussion
According to the calculation results of longitudinal stress ($\sigma_l$) and circumferential stress ($\sigma_c$) in both process and vessel simulation were used to evaluate vessel design, as shown in Table 3. For welding joint area, the length of welding was calculated by considering the working stress at the vessel joint (293.4 in). Thereby, design stress ($\sigma_d$) was 1.977 psi and equivalent stress ($\sigma_{eq}$) was 9409.1 psi or 64.8 Mpa.

Table 3. Results of stress calculation for shell and head vessel design

| Components   | $\sigma_e$ (psi) | $\sigma_d$ (psi) |
|--------------|-----------------|-----------------|
| Shell        |                 |                 |
| process      | 37725.53        | 7545.10         |
| vessel       | 28968.69        | 5793.73         |
| Head         |                 |                 |
| cone         | 7545.10         | 15090.21        |
| conical      | 3450.27         | 6900.54         |
| flat         | 28968.69        | 0               |

The result of equivalent stress ($\sigma_{eq}$) from the model simulation was evaluated in design and operation respectively, as shown in Fig. 5. The material strength at temperature design ($S_d$) was 116 Mpa.

Figure 4. Simulation results of vessel design for two types model, (a), (b), (c), (f), (i), (j) simplified design and (c), (d), (g), (h), (k), (l) proposed design model in design and operation condition.
In the computation, simulation simplified model of vessel and proposed vessel model were compared. The vessel model was evaluated in two conditions, in design and operation. In design condition, the loading parameter for the simplified model was performed either at internal pressure (5 bar) or external pressure (3 bar) as well in both combination internal and external pressures, as shown in Fig. 4 (a), (b), (e), (f), (i), and (j). In operation condition, the loading parameter for the proposed model was performed either at internal pressure (3 bar) or external pressure (1 atm) as well as a combination in both internal and external pressures, as shown in Fig. 5 (c), (d), (g), (h), (k), and (l).

For the analytical calculation of vessel design \( \sigma_{vm} \leq S_\alpha \), the result was \( \sigma_{vm} = 64.8 \) MPa, and allowable stress material \( (S_\alpha) \) in design was 116 MPa. Meanwhile, the model simulation result was required to meet simplified model stress \( (M_{mean}) \leq S_\alpha \), \( M_{mean} \) of 56.91 MPa and \( S_\alpha \) of 116 MPa (Table 4). The vessel design was obtained to proposed model stress \( (K_{mean}) \leq S_\alpha \), \( K_{mean} \) of 86.13 MPa and \( S_\alpha \) is 116 MPa (Table 5). It can be concluded that the proposed model is acceptable to be manufactured.

### Table 4. Results of pressure calculation for simplified model design

| Pressure load | Condition                  | Pressure (MPa) | Highest pressure (MPa) | Lowest pressure (MPa) | Average \( (K_{mean}) \) | \( S_\alpha \) (MPa) |
|---------------|----------------------------|----------------|------------------------|-----------------------|---------------------------|---------------------|
| 5 bar ; 0 atm | Internal pressure design   | 96.96          | 96.96                  | 27.43                 | 56.91                      | 116                 |
| 3 bar ; 0 atm | Internal pressure operation| 58.17          |                        |                       |                           |                     |
| 0 bar ; 3 atm | Internal pressure design   | 82.29          |                        |                       |                           |                     |
| 0 bar ; 1 atm | Internal pressure operation| 27.43          |                        |                       |                           |                     |
| 5 bar ; 3 atm | Design pressure            | 38.27          |                        |                       |                           |                     |
| 5 bar ; 1 atm | Actual operation pressure  | 38.39          |                        |                       |                           |                     |

### Table 5. Results of pressure calculation for the proposed model design

| Pressure load | Condition                  | Pressure (MPa) | Highest pressure (MPa) | Lowest pressure (MPa) | Average \( (K_{mean}) \) | \( S_\alpha \) (MPa) |
|---------------|----------------------------|----------------|------------------------|-----------------------|---------------------------|---------------------|
| 5 bar ; 0 atm | Internal pressure design   | 113.20         |                        |                       |                           |                     |
| 3 bar ; 0 atm | Internal pressure operation| 67.93          |                        |                       |                           |                     |
| 0 bar ; 3 atm | Internal pressure design   | 125.2          |                        | 125.2                 | 41.72                     | 86.13               |
| 0 bar ; 1 atm | Internal pressure operation| 41.72          |                        |                       |                           |                     |
| 5 bar ; 3 atm | Design pressure            | 81.28          |                        |                       |                           |                     |
| 5 bar ; 1 atm | Actual operation pressure  | 82.10          |                        |                       |                           |                     |

### 4. Conclusion

The portable vessel design of distilled patchouli oil based on vacuum technology has been designed and evaluated. It was developed to substitute the current design in order to increase the reliability and the quality of the final distilled oil products. Calculation and simulation for proposed vessel design should meet the allowable standard. For analytical calculation \( \sigma_{vm} \leq S_\alpha \), \( \sigma_{vm} \) was 64.87 MPa, and allowable stress material \( (S_\alpha) \) in the design condition was 116 Mpa. Therefore, the proposed vessel design was more appropriate to apply in a portable patchouli oil steam boiler and suitable for manufacturing stages.
5. Reference

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