Exergetic and Energetic Analysis of a Traditional Semi-Industrial Comorian Ylang-Ylang Essential Oil Wood Fire Distiller

Malik E. Ahamadi, Abderemane Saindou, Hery T. Rakotondramiarana

Abstract—In this article, a study of the energy performance of a distillation system of ylang-ylang essential oil on a wood fire was carried out. To do this, an analysis using the first and the second law of thermodynamics was made for each component of the distillation system. The analysis showed that the energy efficiency depends on the fraction of oil to be distilled and that the whole system is very deficient. The exergetic and energetic analysis shows that it is in the combustion chamber that has a large amount of destroyed exergy and a strong energetic loss. The velocity of the air entering at the combustion chamber greatly influences the efficiency of the chamber. Indeed, it has been found that, the destruction of the exergy in the combustion chamber increases with the velocity of the incoming air.

Index Terms—Exergetic Efficiency, Energetic Efficiency, Wood Fire, Ylang-Ylang Essential Oil.

I. INTRODUCTION

In Comoros, the environmental degradation is a worrying subject whose effects become more and more visible. We can see the extent of natural disasters that are gaining ground, such as rising sea levels, landslides, floods and others. In Anjouan Island, deforestation is one of the major causes of environmental degradation. Among the causes of deforestation, firewood is at the top of the list and the major part of which is used in the distillation of ylang-ylang essential oil [1]-[2]. Although Comoros is one of the world’s leading producers of ylang-ylang, distillation methods are still traditional. These models are made of a combustion chamber whose fuel is wood, a cucurbit serving as a boiler and a condenser. The biggest difference from most of the world’s essential oil distillers is that the one studied in this work is manufactured without any standard to optimize energy efficiency. It is worth noting that a large quantity of fuel is used for each distillation operation. Nowadays, there is almost no fuel, hence the need for such a study. In the literature, several studies are cited on the energy and the exergy analysis of boilers using different types of fuels. Indeed, the exergetic analysis is a powerful tool for the evaluation of the energy quality and an efficient optimization of energetic systems. However, none of these works studies the particular case of Comorian boilers. Pal et al. [3] have studied the energetic and exergetic analysis of a boiler and a turbine of coal fired. It follows from their study that; the irreversibility is maximum in the boiler than in the other components of the system. Studies carried out by Ohijeagbon et al. [4] on the exergetic modelling of a steam boiler of oil fire shows that the destroyed exergy in the boiler decreased to 14.6% as the evaporation ratio increased from 10 to 14. The authors showed that the major area to control irreversibility resulting from entropy effects is the combustion product entropy which leads to increased exergy destruction in combustion unit. Other studies show that the maximum of exergy destroyed on steam production systems is always observed on the boiler. It is the case study of Naik et al. [5] research on the exergetic analysis of 4.5 mw of biomass based steam power plant. The study conducted by Pattanayak [6] on the energetic and exergetic analyses of pulverized coal fire boiler shows that the combustion chamber is the major contributor of exergy destroyed in the boiler. Several works have shown the significant destruction of exergy in the boiler. The actual losses are first over the boiler where the entropy is produced [7]. Therefore, it is not reasonable to take advantage of the energy lost in the condenser [8] in [7]. In the present work, we are going to make an energy and exergy analysis of a Comorian traditional ylang-ylang essential oil distillation system. This analysis is essential insofar as it will allow us identifying the parts of the system with a high energy degradation for a good optimization. The particularity of our work resides in the fact that the traditional chamber of combustion is badly insulated and the boiler consists of a cucurbit where there is a mixture of a water and ylang-ylang flowers, which generates a mixture of steam and oil. We did an energy and exergy analysis on each component of the distillation system and run simulations to see the energetic and exergetic behavior of the system with respect to each fraction of essential oil; knowing that is distilled into four fractions: the extra superior fraction (ES), the extra fraction (E), the first fraction (I), the second fraction (II) and the third fraction (III). Each of these fractions has its own characteristics and its duration of distillation. The energy efficiency and the exergy efficiency change according to the fraction of oil to be distilled.

II. METHODS

A. System presentation

The studied system is a traditional ylang-ylang essential oil distiller. It consists of a combustion chamber, a boiler
and a condenser (Fig.1). The combustion chamber is a brick furnace or cement stones where a door used to supply the fuel chamber is always open throughout the distillation operation. A cucurbit serving as a boiler where the ylang-ylang flowers are located is embedded directly in the combustion chamber (Fig. 2).

![Distillation process diagram](image1)

**Fig. 1. Distillation process diagram**

![Traditional combustor chamber](image2)

**Fig. 2. Traditional combustor chamber**

### B. Exergy concept

The exergetic analysis is a methodology of evaluation of the performances of a system or process. The evaluation of the exergy of different subsystems at different points of an energy chain makes it possible to evaluate the efficiency of the system. An understanding of energetic efficiency and exergetic efficiency is needed for the design, analysis, optimization and improvement of energy systems. The exergetic analysis is based on the second principle of thermodynamics (Carnot principle) to quantify the amount of energy. According to this principle, there is always an irreversible thermal energy dissipation during a physical phenomenon which is due to the disorder of the system. According to Carnot, it is possible to convert heat into work, but only a part of this heat can be convert into mechanical energy. This heat loss is defined by relation (1):

\[ \eta = 1 - \frac{T_f}{T_c} \]  

(1)

Where, \( T_f \) and \( T_c \) are respectively the cold heat source temperature, and the hot heat source temperature. Thus, the knowledge of the mechanical energy that can be produced by a system is given by a state function introduced by the second principle called entropy \( S \) usually assimilated to the notion of disorder which can decrease during a real transformation. From the view point of thermodynamics, exergy is defined as being the maximum amount of work that can be produced by a system, or a stream of matter or energy so that it is in equilibrium with a reference environment [9] in [10].

### C. The reference environment

As previously stated, exergy is always defined from a reference environment. This latter is in stable equilibrium and acts as a system to infinity and constitutes a well or a source of heat or matter [11]. This, implies that parameters such as temperature or pressure are assumed to be constant in this reference environment.

### D. Energy balance of combustion chamber

Our objective is to do an energetic and exergetic study of the combustion chamber of traditional Comorian still and to identify the weaknesses in the system so that they can be remedied. Thus, we will start our study with an energy balance of the combustion chamber. The traditional still combustion chamber is not insulated. Thus, a part of the energy produced by the wood combustion is transferred to the external environment by conduction through the walls of the chamber (in brick), but especially by radiation through the door of the combustion chamber which is always left open. In this study, we will consider these losses. Fig.2 shows a model of the combustion chamber. The energy balance of the chamber is that modeled in Fig. 3. In the energy balance, we neglect the potential energy and the kinetic energy of fluids in combustion chamber. By applying the first principle of thermodynamics, we can establish the energy balance of the combustion chamber. Thus, considering a mass flow of combustible \( m_f \), a mass flow of air \( m_a \), and a mass flow of products \( m_p \), the energy balance is written as:

1) **Continuity equation:**

\[ m_f + m_a = m_p \]  

(2)

2) **Energy balance:**

\[ \dot{E}_{in} - \dot{E}_{out} = 0 \]  

(3)

Whether,

\[ m_f h_f + m_a h_a - m_p h_p - \sum_i Q_{i\epsilon} = 0 \]  

(4)

Thus,

\[ m_p h_p = m_f h_f + m_a h_a + \sum_i Q_{i\epsilon} \]  

(5)

Where \( \sum_i Q_{i\epsilon} \) is the sum of calorific energy losses through the insulated walls of the chamber and the open door of the chamber.

In equation (5) \( h_f, h_a, h_p \) are respectively the fuel enthalpy (wood), the air enthalpy and the product enthalpy. On the previous energy balance, the efficiency of the combustion chamber is defined by:

\[ \eta_c = \frac{m_p h_p}{m_f h_f} \]  

(6)
The specific enthalpy of fuel is evaluated such that it is the highest heating value (HHV). BEESP [12] in [13] gives a value of wood fire fuel of HHV_w = 13794 kJ/kg. The efficiency defined by equation (6) is 100% for an adiabatic chamber. In this study, the combustion chamber is not adiabatic.

E. Exergetic analysis of combustion chamber

Two important parts compose the exergy: the chemical exergy and the physical exergy. In this work we neglect the exergy due to the kinetic energy and gravity potential energy [14]-[15]. Physical exergy is defined as the maximum theoretical work that is useful for the system interacting with an equilibrium state. As for the chemical exergy, it is associated with the deviation of the chemical composition via its chemical equilibrium equation. In combustion process chemical exergy is very important. Usually, exergy is destroyed and not conserved as energy. Destroyed exergy is the measure of irreversibility which is the source of lost system performance [16] in [10]. The variation of the exergy of a system during a process is equal to the difference between the net exergy flows across the system frontiers as the results of the irreversibilities.

![Fig. 3. Schematic energy flow diagram of combustion chamber](image)

1) Chemical exergy of wood combustion

To do an energetic analysis of wood combustion, we need to know the chemical composition of the wood. Average values were theoretically increased in the case of dry wood with 25% moisture content by Carvalho et al. [17] in [13] based on the baseline data that are collected by BEESP [12] et BEN [18] and who took into account this humidity in their studies. The average chemical composition of wood combustion to humidity of 25% is given in Table 1 from the following chemical equilibrium equation [13]:

\[ C_3H_7.3O_{0.5} \rightarrow 3.1O_2 + 11.7N_2 \rightarrow 3CO_2 + 3.65H_2O + 11.7N_2 \]  

<table>
<thead>
<tr>
<th>TABLE 1. FIRE WOOD CHEMICAL COMPOSITION</th>
<th>Composition in mass (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Dry</td>
<td>48.0</td>
</tr>
<tr>
<td>25% Humidity</td>
<td>36.0</td>
</tr>
</tbody>
</table>

DIAS et al. [13] adjust the equation proposed by Shieh and Fan [19] to calculate the exergy of the wood fuel for the data of Table 1 and obtain the following equation for the calculation of exergy:

\[ \epsilon_f = 34183.16(C)621.95(N) + 11659.19(H) + 18242.90(S) - 13265.90(O) + 24.91.05(F) + 1174.18(Cl) + 5033.97(Br) + 2894.65(I) - (2598.15\epsilon_{ashes}m_{ashes}) + 0.63(0)7837.667(C) + 3388.889(H) - 4236.10(O) + 3828.75(S) + 4447.37(F) + 1790.90(Cl) + 681.97(Br) + 334.86(I) \]  

In equation (8), the value between parentheses are the percentages by mass of carbon, nitrogen, hydrogen, sulfur, oxygen, fluorine and iodine which make up the combustible; and \( s_{ashes} \) denotes the formation entropy of ashes: 0.84 kJ/kg K while \( m_{ashes} \) represents the mass ashes for a one kilogram of combustible. Taken into account of the values of Table 1 at 25% of humidity, we obtain the exergy of wood fuel combustion:

\[ \epsilon_{wood} = 14515.20 \text{kJ/kg} \]

2) Exergetic analysis

The exergetic balance of the combustion chamber is schematically shown in Fig. 4:

![Fig. 4. Exergy flow diagram of the combustor](image)

The exergetic balance in the combustion chamber can be formulated as follows:

\[ x_{in} - x_{loss} - x_{out} - x_{destroyed} = 0 \]  

Which gives the destroyed exergy:

\[ I_c = m_f \epsilon_f + m_a \epsilon_a - m_p \epsilon_p - \sum_i Q_{ic} \left(1 - \frac{T_o}{T} \right) \]

Where \( T_o \) and \( T \) are respectively the temperatures of the reference environment and the system, \( I_c \) the destroyed exergy and \( \epsilon_f, \epsilon_a, \epsilon_p \) denote the respective exergies of the fuel, the air and the products.

The exergetic efficiency of the combustion chamber is defined in a manner similar to the energy efficiency as follows:

\[ \psi_e = \frac{m_p \epsilon_p}{m_f \epsilon_f} \]
F. Energetic analysis of the boiler

For the traditional model studied in this paper, the boiler is perfectly embedded in the walls of the combustion chamber. Thus, we assume that there is a thermal equilibrium between the walls of the boiler and those of the combustion chamber. However, the boiler lid is not isolated, energy losses are observed to the surrounding environment. Given the small thickness of the sheet forming the cover, the thermal resistance of the cover remains very low which means a large heat transfer between the inside and the outside. We also want to point out that in this traditional Comorian model, steam is not produced from a heat exchanger, but water is introduced directly into the steam generator, which produces steam by heating. As a result, liquid water and steam can coexist. However, we consider that the two phases are always separated.

In all that follows unless otherwise stated, we will assume that the temperature is uniform in the liquid phase and in the vapor phase. Fig. 5 shows all transfers in the system studied here for the boiler.

1) Mass conservation in the vapor phase (dome of the boiler)

The analysis is in steady state. Thus, any variation with respect to time is zero. The conservation equation of mass is:

\[ \dot{m}_{\text{evap}} - \dot{m}_{\text{e}} = 0 \]  (13)

2) Mass conservation in the liquid phase

\[ \dot{m}_{\text{e}} - \dot{m}_{\text{evap}} = 0 \]  (14)

Equations (13) and (14) show us that under these conditions we have:

\[ \dot{m}_{\text{e}} = \dot{m}_{\text{e}} = \dot{m}_{\text{evap}} = \dot{m}_{\text{c}} \]  (15)

Where \( \dot{m}_{\text{e}}, \dot{m}_{\text{c}} \) and \( \dot{m}_{\text{evap}} \) are respectively the input water flow rate, the steam output flow rate and the evaporation rate.

3) Energy balance

Taking into account all the incoming and outgoing flows in the boiler, we obtain the energy balance of the boiler (figure 5):

\[ \dot{m}_p h_p + \dot{m}_e h_e + \dot{Q}_{\text{ilang}} - (\dot{m}_p h_p + \dot{m}_{\text{SO}}(x h_x + (1-x) h_o)) - \dot{Q}_e = \dot{Q} \]  (16)

Where \( \dot{m}_{\text{SO}}, h_o, h_p, x \), and \( \dot{Q} \) are respectively the mass flow rate of the essential oil-vapor mixture, the enthalpy of the vapor phase, the enthalpy of the oil phase, the mass fraction of the vapor phase in the mixture, and the energy lost on the boiler cover ( uninsulated dome) and in the boiler (for example dissipated energy ...) while \( \dot{Q}_{\text{ilang}} \) represents the heat amount received by the ylang-ylang in the boiler. Ylang-ylang is introduced into the boiler at room temperature. Thus, we consider that initially ylang-ylang is at the same temperature as the atmosphere at the time of its introduction into the boiler. Consequently, the heat received by ylang-ylang can be computed by the following relationship:

\[ \dot{Q}_{\text{ilang}} = \dot{m}_{\text{ilang}} c_{\text{ylang}} (T_C - T_0) \]  (17)

The mass flow rate of the essential oil-vapor mixture is given by:

\[ \dot{m}_{\text{SO}} = x \dot{m}_s + (1-x) \dot{m}_o \]  (18)

In the assumption that there is no mixing in the boiler [11] and taking into account equations (14) and (15) we can write:

\[ \dot{m}_p = \dot{m}_g = \dot{m}_H \]  and \( \dot{m}_e = \dot{m}_s = \dot{m}_c. \)

In the present study, the vapor phase is mixed with the oil phase (miscibility), we obtain then the following energy balance for the boiler:

\[ \dot{m}_p (h_p - h_g) + \dot{m}_e h_e + \dot{m}_{\text{ilang}} c_{\text{ylang}} (T_C - T_0) = \dot{m}_{\text{SO}}(x h_x + (1-x) h_o) - \dot{Q}_e = \dot{Q} \]  (19)

The enthalpy of the essential oil of ylang-ylang is evaluated by taking into account the essential components of this oil according to AFNOR for the essential oils of Comoros and Madagascar [20] summarized in Table 2. Thus the enthalpy of the essential oil of ylang-ylang is:

\[ h_o = \sum_i x_i h_i \]  (20)

Where \( x_i \) and \( h_i \) are respectively the mass fraction and the enthalpy of the component \( i \) of the ylang-ylang essential oil. Therefore, the energy efficiency of the steam generator is defined as follows:

\[ \eta_g = \frac{[\dot{m}_p (h_p - h_g) + \dot{m}_e h_e + \dot{m}_{\text{ilang}} c_{\text{ylang}} (T_C - T_0)]}{\dot{m}_f h_f} \]  (21)

The overall energy efficiency of the whole is defined by:

\[ \eta_g = \frac{[\dot{m}_p (h_p - h_g) + \dot{m}_e h_e + \dot{m}_{\text{ilang}} c_{\text{ylang}} (T_C - T_0)]}{\dot{m}_f h_f} \]  (22)

In the exergetic balance, we will take into account the quality of energy lost on the boiler lid in the form of heat. This heat transfer exergy rate will be calculated by means of equation (23) [9]-[21].

\[ \text{exergy rate of heat transfer} = \left(1 - \frac{T_B}{T_C}\right) Q_T \]  (23)
Where $T_B$ and $T_r$ are respectively the temperature of the cold source (here the environment) and the temperature in the boiler and $Q$, the thermal energy.

Thus, we get the expression of the exergy destroyed in the boiler:

$$ I_B = m_i (\epsilon_p - \epsilon_g) + \dot{m}_\epsilon \epsilon_l + \left(1 + \frac{\eta_B}{\eta_C} \right) Q _{lang} - m_{SO} \epsilon_{SO} - \left(1 + \frac{T_B}{T_C} \right) Q_r \quad (24) $$

In this equation $\epsilon_{SO}$ is the exergy of the essential oil vapor mixture which is defined as follows:

$$ \epsilon_{SO} = \sum_i x_i \epsilon_i \quad (25) $$

Where $\epsilon_i$ is the specific exergy of the component $i$ in the control volume and $x_i$ its mass fraction.

In the liquid phase the entropy of a component can be evaluated by equation (26) [22]:

$$ S_l = C_{plI} \ln \left( \frac{T}{T_0} \right) \quad (26) $$

For a component in the gas phase, the entropy is given by equation (27):

$$ S_g = C_{plg} \ln \left( \frac{T_{vap}}{T_0} \right) + S_{lv} + C_{psg} \ln \left( \frac{T}{T_0} \right) \quad (27) $$

In which $S_g$ is the specific entropy of the component in the gas phase and $S_{lv}$ the corresponding vaporization entropy.

Assuming that the entropies are evaluated by considering the reference state $P_0 = P_{atm}$ and $T_0 = T_{amb}$ the physical exergy of a liquid component $i$ in the control volume is given by equation (28):

$$ \epsilon_{li} = h_{li} - T_{amb} S_{li} \quad (28) $$

$h_{li}$ is the specific enthalpy of the component $i$ found in the control volume in the liquid phase and $S_{li}$ respectively the specific entropy. An analogous expression expresses the entropy of component $i$ in the gas phase:

$$ \epsilon_{gi} = h_{gi} - T_{amb} S_{gi} \quad (29) $$

If components are present in the liquid phase and in the gaseous phase, the exergy of the assembly is formulated as follows:

$$ \dot{\epsilon} = m_{SO} (\sum x_l \epsilon_{li} + \sum x_g \epsilon_{gi}) \quad (30) $$

The performance of the boiler is defined in a similar way as the previous cases (equation 32). The total destroyed exergy of the boiler-combustion chamber assembly is obtained by summing the destroyed exergy of the combustion chamber with that of the boiler. Thus, we obtain:

$$ I = I_B + I_C \quad (31) $$

As for the energy efficiency of the boiler, it is defined by:

$$ \psi_B = \frac{m_{HR} \epsilon_{HR} + m_{SO} \epsilon_{SO}}{m_{HR} \epsilon_{HR} + (1 - \frac{T_B}{T_C}) Q_{lang} + mC \epsilon_l} \quad (32) $$

G. Energetic analysis of the condenser

The condenser of the traditional Comorian still is a heat exchanger consisting of a metallic cylinder of about 1 m$^3$ of volume where the cold water is located and a coil or two tubes inside the cylinder that circulate at the vapor to be condensed. In this study, we will consider the tube exchanger that is most common among users. More precisely, it is a countercurrent exchanger. Indeed the cold water is brought in by the lower level of the exchanger while the steam is entered by the higher level of the exchanger.

The studied exchanger is not thermally insulated. Thus, the energy balance that we will do will take into account the energy transfer from the exchanger to the ambient environment by conduction through the metal walls of the exchanger. Fig.6 shows a model of the exchanger.

Fig.6. The system's heat exchanger

| TABLE II: REPRESENTATIVE CHARACTERISTIC COMPONENTS OF YLANG-YLANG ESSENTIAL OILS FOR EACH FRACTION OF EACH ORIGIN (AFNOR) [20] |
|---|---|
| Cons tituents (% of air) | Fractions |
| Co | Co | Mad | Mad | Co | Mad | Co | Mad | Mad |
| Mono | Mono | Gases | Mono | Gases | Mono | Gases | Mono | Gases |
| Ros | Ros | and | Ros | and | Ros | and | Ros | and |
| Ma | Ma | and | Ma | and | Ma | and | Ma | and |
| Yott | Yott | and | Yott | and | Yott | and | Yott | and |
| Acétate de prényle | Min. | 1.5 | 1.0 | 0.6 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 |
| Max. | 3.2 | 2.3 | 2.2 | 1.8 | 1.0 | 0.9 | 0.5 | 0.2 | 0.2 |
| Ether de p-cresyl méthyl | Min. | 7.0 | 5.0 | 7.0 | 3.0 | 5.0 | 2.0 | 1.0 | 0.1 | 0.1 |
| Max. | 13. | 13. | 16.0 | 8.5 | 10.0 | 5.0 | 4.6 | 1.0 | 1.4 |
| Benzoate de méthyle | Min. | 4.5 | 4.0 | 4.5 | 1.5 | 3.0 | 1.0 | 1.0 | 0.1 | 0.1 |
| Max. | 8.0 | 6.5 | 9.0 | 5.5 | 5.0 | 3.5 | 3.0 | 0.8 | 0.9 |
| Linanol | Min. | 8.0 | 7.0 | 15.0 | 3.0 | 12.0 | 2.0 | 4.0 | 0.1 | 0.6 |
| Max. | 13. | 12. | 24.0 | 10.0 | 1.9 | 6.0 | 9.5 | 2.0 | 4.0 |
| Acétate de méthyle | Min. | 14. | 11. | 5.5 | 6.0 | 2.8 | 4.0 | 0.5 | 0.5 | 0.1 |

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The energy balance for the condenser is then written:
\[
\dot{m}_e'(h_1 - h'_1) - (\dot{m}_e''e' + m_{ao}h'_o - \dot{m}_{so}h_{so}) - Q_c = 0
\]
(33)

Where,
\[
h_{so} = xh_a + (1 - x)h_o
\]
(34)

In which \(h'_o, h'_1, h_{so}, \dot{m}_e', \dot{m}_o, \dot{m}_e''\), \(Q_c\), are respectively the enthalpy of the distillate oil, the enthalpy of the distillate water, the enthalpy of hot water (output of the BAC), the mass flow of the water entering and leaving the tank (mass conservation), the mass flow rate of the distilled oil, the mass flow rate of the condensed vapor (condenser outlet), the heat transferred to the ambient medium by conduction through the walls of the condenser.

The energy efficiency of the heat exchanger can be defined by the following relationship (the energy efficiency of the heat exchanger is defined as being the ratio between the heat flow rate received by the secondary fluid (treated fluid) and the flow rate of heat transported by the primary fluid (fluid used as a treatment)) [23]. In our case the fluid to be treated is the vapor, thus it is the secondary fluid and the fluid used for the treatment is cold water, it is then the primary fluid):

\[
\eta_e = \frac{\dot{m}_{so}h_{so} - (\dot{m}_e''e' + \dot{m}_{ao}h'_o)}{\dot{m}_e'(h'_1 - h_1)}
\]
(35)

H. Second low analysis of the condenser

As in the previous paragraphs, we will take into account the exergy due to the heat transfer to the environment through the walls of the exchanger. Thus, the exergy destroyed in the exchanger is:

\[
I_e = \left(1 - \frac{T_{ref}}{T_e}\right)Q_c + \dot{m}_e'\varepsilon' (e'_1 - e_1) - (\dot{m}_e''e' + m_{ao}e' - \dot{m}_{so}e_{so})
\]
(36)

It gives an exergy to the exchange rate; this is the ratio between the variation of the exergy of the secondary agent (secondary fluid) and the variation of the exergy of the primary agent (primary fluid) [23]:

\[
\psi_e = \frac{\dot{m}_e''e' + m_{ao}e' - \dot{m}_{so}e_{so}}{\dot{m}_e(e_1 - e'_1)}
\]
(37)

And the total exergy of the system (combustion chamber + boiler + condenser) is the sum of the three previously defined exergies:

\[
I_g = I_e + I_H + I_C
\]
(38)

III. RESULTS AND DISCUSSIONS

For a complete distillation on average the distillers use 4m³ of wooden stele. That means 4m³ of air and wood. The average distillation time for all fractions combined is 72hours [1]. In our work, we will consider logs of wood about 23cm in diameter which corresponds to a volume of 0.68m³ of wood per 1m³ of stele (wood + air) [24]. For the calculation of the enthality and entropy of each oil fraction, we used the data in Table 2. The data for each component in each fraction are those of Eugene et al. [25].

A. Influence of the air velocity on the exergy destroyed in the combustion chamber

Fig.7 shows the evolution of exergy destroyed in the combustion chamber as a function of the air velocity. It can be seen in this figure that the destroyed exergy increases with the speed of the air entering in the chamber. Irreversibility represents the energy that could have been converted into work but that was not. Thus, the results obtained in figure 7 clearly show that the speed of the air entering in the combustion chamber (hence the flow rate) has a great influence on the energy deficiency of the combustion chamber. Putting doors with thermal insulation seems necessary to be able to recover these irreversibilities.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Min.</th>
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<th>0</th>
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<th>10</th>
<th>15</th>
<th>20</th>
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<td>Géranol</td>
<td>0.1</td>
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<td>Salicylate de benzy1e</td>
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<td>4.0</td>
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<td>5.0</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
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<tr>
<td>(\dot{m}<em>e''e' + m</em>{ao}e' - \dot{m}<em>{so}e</em>{so})</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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B. Destroyed exergy in the boiler as function of each oil fraction distilled

Fig. 8 shows the evolution of exergy destroyed in the boiler according to each fraction of essential oil. It can be seen that the exergy destroyed substantially varies with the fraction of essential oil. For the first two fractions irreversibility is lower compared to the last two fractions. One can observe a very great destruction for the first fraction.

C. Destroyed exergy in the condenser as a function of the oil fraction distilled

Fig. 9 shows the irreversibilities in the heat exchanger as a function of the fraction distilled oil. As in the previous paragraph, we can see that it is during the distillation of the first fraction that the destroyed exergy reaches its maximum. Then follows the distillation of the third fraction while the second fraction is the one whose destroyed exergy is minimal in the condenser. During the distillation of the first two fractions the exergy destroyed is minimal. Indeed, at the beginning of the distillation, the treatment fluid is still cold which can explain this. On the other hand, during the distillation of the other three fractions, the treatment fluid being very hot, this increases the irreversibility.

D. Comparison of the energetic efficiency and exergetic efficiency of the combustion chamber

Fig. 10 shows a comparison between the energy efficiency and the exergetic efficiency of the combustion chamber. As can be seen, the yields are very low of the order of 0.1% for the exergetic performance and 1.07% for the energy efficiency. These results show us the bad technology in the manufacture of these combustion chambers. On the other hand, the efficiency of the chamber is not only based on the specific energy entering into the boiler but also on the lower value of heating the fuel to constitute losses occurring in the boiler due to the energy lost with lime gases and incomplete combustion. Exergetic losses can provide measures of ideality approaches or deviation from ideality.

E. Energetic and exergetic efficiency of the boiler for each fraction of essential oil

Fig. 11 and Fig. 12 show the results on the, energetic and exergetic, efficiencies of the boiler for each fraction of
essential oil. It can be seen that the boiler still has a better performance compared to the combustion chamber. However, it is a return that remains as low as 10%. Indeed, the boiler is not thermally insulated which causes huge energy losses to the environment by conduction through the walls of the boiler. As for the exergetic efficiency, it is of the order of 2.75%. A yield that is lower than energy efficiency. We can also note that, if the energetic efficiency increases, so does the exergetic efficiency. It follows from all these results that a large quantity of exergy is destroyed in the energetic system constituting the whole of the distillation of ylang-ylang essential oils.

F. Energetic and exergetic efficiency of the condenser for each fraction of essential oil

Fig. 13 and Fig. 14 show the results on the energy and exergetic efficiencies of the condenser. The condenser has a very low energy efficiency as can be seen in Figure 13. This can be explained by the fact that its systems are often poorly sized, hence the condensation is not done as it should. This phenomenon can be directly observed on the distillation sites. Another striking point is the fact that the energy efficiency approximates the exergy efficiency for the third fraction and exceeds it for the first fraction. This shows us that during the distillation of the first fraction, there is less irreversibility than during the distillation of the other fractions.

IV. CONCLUSION

In this work, an energetic and exergetic analysis was carried out for a Comorian ylang-ylang essential oil distillation system. The fuel used in this process is wood. The analysis was performed for each component of the distillation system ranging from the combustion chamber to the condenser. It follows from the obtained results that it is in the combustion chamber that great energy losses and significant irreversibilities occur. However, the entire system shows that it is very deficient on energy. The analysis of the results for each essential oil fraction (extra superior fraction, extra, first fraction, second fraction and third fraction) shows that significant irreversibilities occur during the distillation of the first fraction and the third fraction. These results show the need for an energy optimization of ylang-ylang essential oil distillation systems for environmental as well as economic concerns. The insulation of the combustion chamber and the boiler seems necessary for a better energy efficiency. The technical and economic optimization of Comorian ylang-ylang distillation systems will be the subject of future work.
systems will be the subject of our next research work, which is one of the perspectives of this work.

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