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Production of a biofuel from biomass and comparative study of the nature of combustion gas emissions from bioethanol and a fossil fuel

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Abstract--Our study is part of the energy transition and the search for sustainable solutions for the transport sector. Bioethanol represents a real opportunity to reduce our carbon footprint and promote a greener and more responsible economy. Its large-scale use can help mitigate the environmental impacts of the transport sector while diversifying our energy supply. The experimental study conducted in our laboratory aimed to explore the production of alcohol from a biomass rich in sugar (38%), this is the case of carob, which is a fruit from the carob tree growing mainly in Mediterranean regions. The sugar conversion reaction is an alcoholic fermentation reaction in anaerobiosis thus transforming fermentable sugars by yeasts into an alcohol and a carbon dioxide with release of calories according to the following reaction:

Sugars + Yeasts Ethanol + CO2 + Energy

The observation of the fermentation parameters (pH, T°, Refractive index, conductivity, CO2 release) revealed an increasing alcohol production over time, thus confirming the proper progress of the fermentation process.

In addition, a MATLAB-based approach was carried out, this study allowed us to accurately model the combustion processes, calculate exhaust emissions and visualize the results in a clear and concise manner. This MATLAB-based approach offers an in-depth understanding of the differences between gasoline and bioethanol in terms of gas emissions, which is crucial to assess their environmental impact and make informed decisions for the development of more sustainable fuels. This part of the research, demonstrate that the higher of the percentage of bioethanol in fuel blends, the more significantly the CO_2 emissions decrease. In fact, we observed a reduction in CO_2 emissions from $10{,}000.10^{-}$kg of CO_2/J to 4,200. 10^{-13} kg of CO_2/J. These results highlight the potential of bioethanol to reduce the environmental impact of transportation.

Keywords : pollution, sustainable fuel, biomass, substrates, bioethanol, CO_2 emissions, fuelblends, environmental impact.

I. INTRODUCTION

The fuel sector is facing major challenges in terms of environmental sustainability and dependence on fossil resources. In this context, bioethanol is emerging as a promising alternative, offering the possibility to reduce greenhouse gas emissions while diversifying energy sources. This work focuses on the production of bioethanol from sugar-rich biomass (30%) highlighting its potential as a renewable fuel. This study is part of the energy transition and the search for sustainable solutions for the transport sector. Bioethanol represents a real opportunity to reduce our carbon footprint and promote a greener and more responsible economy.

The aim of this study is to provide an in-depth analysis of the production and use of bioethanol with a focus on its environmental advantages over other fuels. We will also address the technical and economic aspects related to bioethanol production, as well as the future prospects for its large-scale use [1].

By closely examining the combustion gas emissions, we will seek to demonstrate that bioethanol has intrinsic characteristics that make it a less polluting fuel than traditional fossil fuels. We detail the methods and equipment used in the experimental part as well as the different stages of bioethanol production from the raw material to ensure the good quality of the bioethanol produced [2].

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The following curve shows global primary energy consumption, which has grown steadily over the decades, reaching 14.3 Gtoe in 2018, twice as much as in 1978. Asia became the main contributor with 41% of global consumption, while Europe, North America and Russia saw their share decrease to 38%. Africa and Latin America recorded faster growth, although their contribution remains modest [3].

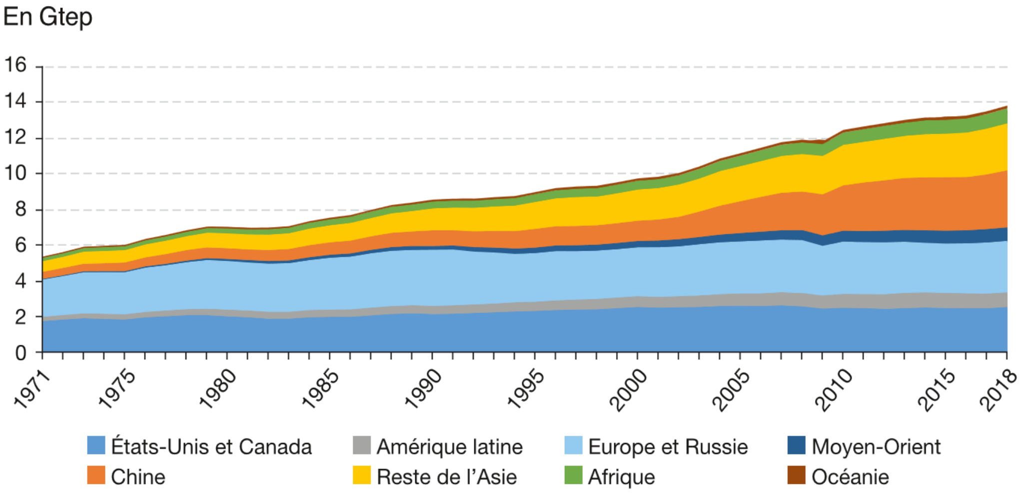

Fig. 1 Global primary energy consumption by geographic area [4].

The characteristics of a fuel [4]:

*Calorific value : Higher calorific value (HCV) and Lower calorific value (LCV);
* Density ;
*Relative density [8] ;
*Flash point [10] ;
*Auto-ignition temperature [8] ;
*Viscosity [8]
*The vapor density ;
*The vapor pressure [8] ;
*Octane rating [10] ;

Bioethanol fuel

Ethanol is also known as ethyl alcohol. Its molecular formula is CH_3CH_2OH. It is a type of ethanol produced by fermentation of biomass (carob). Currently, bioethanol is the most commonly used liquid biofuel across the world. It is mainly produced using microbial fermentation of sugar or starch from various sources such as sugarcane, sugar beet, corn, cereals, agricultural waste, forest waste, municipal waste, livestock manure, etc [5].Bioethanol can be used directly as a substitute for gasoline in engines. Table I.1 shows the physicochemical properties of gasoline and bioethanol.
It is remarkable that the calorific value of ethanol is lower than that of gasoline (21.1 MJ/L versus 30-33 MJ/L), meaning that more ethanol is needed to produce the same amount of energy.

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However, the higher octane rating of ethanol allows a higher compression ratio to be used in the engine, which improves thermal efficiency and power, thus reducing the difference in fuel consumption [6,7] .

TABLE 1 Physicochemical properties of gasoline and ethanol [4]

Properties	Essence	Ethanol
Formula	C4 to C12	C2H5OH
Molecular weight	100–105	46.07
Density at 15°C (Kg/L)	0.69–0.79	0.79
Relative density at 15°C	91	106-110
Freezing point (°C)	-40	-114
Boiling point (°C)	27-225	78
Vapor pressure at 38°C (KPa)	48-103	15.9
Specific heat (Kj /Kg/K)	2.0	2.4
Viscosity at 20°C (mPa.s)	0.37-0.44	1.19
Lower calorific value (Kj /L)	30-33	21.1
Flash point (°C)	-43	13
Auto-ignition temperature (°C)	257	423
Lower flammability limit (% vol)	1.4	4.3
Upper flammability limit (% vol)	7.6	19.0
Stoichiometric air-fuel ratio	14.7	9.0
Research Octane Index	88-100	108.6
Engine octane rating	80-90	89.7

The consumption of one liter of bioethanol produces on average 1.87 kg of CO_2, compared to 2.28 kg of CO_2 for petrol [8,9] . This difference is explained by the fact that bioethanol comes from the photosynthesis of plants, which capture CO_2 from the air. However, we must also take into account the emissions linked to the manufacture and transport of bioethanol, which can be significant depending on the source of the biomass and the process used [10,11] . Bioethanol also releases local pollutants such as NO_x (nitrogen oxides), CO (carbon monoxide), HC (unburned hydrocarbons) and PM (fine particles). These pollutants are harmful to health and the environment. According to the IFPEN study, bioethanol produces on average 20 mg/km of NO_x, compared to 57 mg/km for diesel and 10 mg/km for NGV (natural gas vehicle). It also produces 1,000 mg/km of CO, compared to 500 mg/km for diesel and 200 mg/km for CNG. It still produces 100 mg/km of HC, compared to 50 mg/km for diesel and 20 mg/km for CNG. Finally, it produces 0.5 mg/km of PM, compared to 1 mg/km for diesel and 0.1 mg/km for CNG [12,13] .

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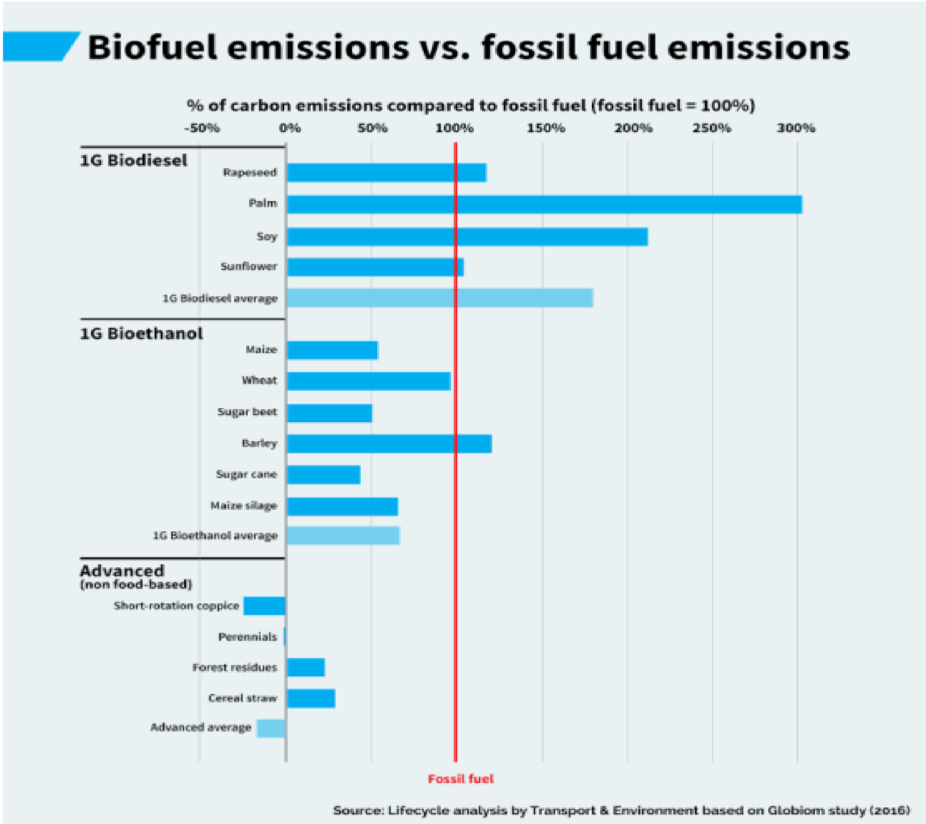

Fig. 2 Carbon emissions compared to fossil fuels [4]

II. MATERIALS AND METHODS

The Carob

Carob is a fruit from the carob tree that grows mainly in Mediterranean regions. It is also rich in dietary fiber, sugar and calcium. Carob has a sugar content of about 38 grams per 100 gram serving and it can vary slightly depending on factors such as variety, growing conditions and drying process. (Valorization of carob molasses by a biorefinery approach). Carob must be ground and chopped to obtain a fine powder, allowing better extraction of the fermentable components[14,15] .

Fig. 3 Carob

Fig. 4 Crushed carob

Yeast

Baker's yeast, specifically Saccharomyces cerevisiae, has been used as a fermentation reagent due to its ability to ferment sugars and produce ethanol. It works by converting sugars present in raw materials into bioethanol through its fermentative metabolism.

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Distilled water

Distilled water was used as a solvent to mix the different raw materials in the fermentation process. It helps create a suitable environment for the yeast to act and convert the sugars into bioethanol.

Fermentation protocol

- After dividing the mixture, we close the mouths of each flask. In the first flask, we use a degassing valve attached to a thin tube, which is then immersed in a test tube containing 50 ml of water. This configuration allows the gases produced during fermentation to be degassed. In addition, we place the probe of a conductivity meter in this test tube to continuously measure the conductivity of the water.
  In the second flask, Through the first mouth of the flask, we insert a pH meter probe to continuously monitor pH variations during fermentation. In the second mouth of the flask, we insert a conductivity meter probe to measure the conductivity of the mixture.
- Once the two flasks containing the substrates and the monitoring devices are prepared, we place the flasks in a water bath and maintain the temperature of the fermentation medium between 30 and 34 degrees Celsius on a shaker to promote a homogeneous distribution of the nutrients.
- As soon as we activate the devices, fermentation is started, we take measurements and record them every hour for three days[16] .

Fig. 5 Fermentation protocol

Distillation

Distillation is a separation process that involves heating a liquid mixture to vaporize the volatile compounds and separate them from the other constituents of the mixture. Then, the vapors are cooled and condensed to obtain a distillate[8] .

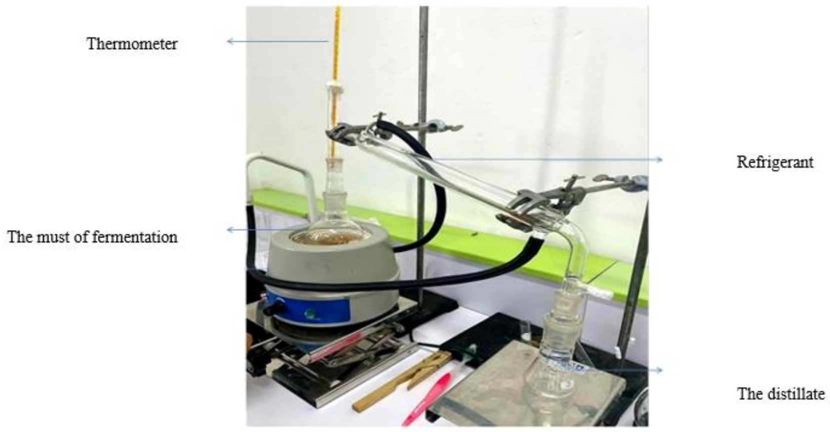

Fig. 6 Distillation setup

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III. RESULTS AND DISCUSSIONS

Analyzing the results from alcoholic fermentation, we will present in detail the experimental data relating to the production of bioethanol by this biological process.

1. During alcoholic fermentation, various changes can be observed, including:

- The release of carbon dioxide (Observation of bubbles forming in the water).
- The increase in the temperature of the environment.
- Accentuation of the color of the liquid.
- The change in smell and taste. Initially, the liquid is sweet, then as fermentation progresses, it becomes more and more alcoholic and acidic.
- The decrease in the density of the liquid due to the transformation of sugars into alcohol.
- The formation of a cap during fermentation.

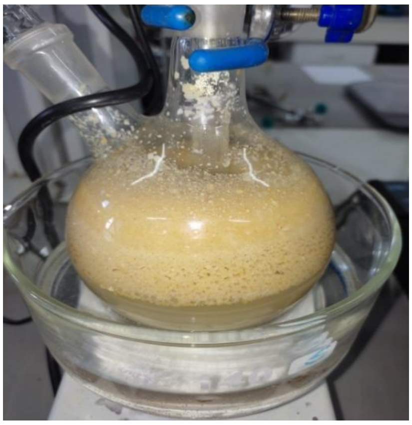

Fig. 7 Formation of must cap

- The increase in the volume of the liquid due to the increase in temperature and the escape of carbon dioxide.

2. Monitoring the evolution of PH during alcoholic fermentation:

At the beginning of fermentation, the pH of the medium is usually slightly acidic, because the raw materials contain organic acids. This results in a lower pH value. As fermentation progresses, the yeast converts the sugars present in the raw materials into alcohol and carbon dioxide, also releasing acidic compounds. This results in a decrease in pH during the first hours of fermentation[8] .

3. Monitoring the variation of mixing conductivity during alcoholic fermentation

At the beginning of fermentation, yeast metabolizes the sugars present in the substrate, producing alcohol and carbon dioxide. This metabolic process results in the production of ions. This chemical transformation leads to an increase in the concentration of ions in the mixture which contributes to the increase in conductivity.

Regarding the second part of our study is focused on the comparative analysis of CO_2 gas emissions between bioethanol, gasoline and their blends, this study has given significant results[9].

Our results showed a progressive decrease in these emissions with the increase in the proportion of bioethanol in the fuel blends, it is also important to emphasize that although our carbon quantity results are minimal on an individual scale, they take on their full importance when cumulated by many cars. This highlights the significant impact that these small quantities can have on a large scale on CO_2 emissions and therefore on the environment[14,15] . This finding reinforces the importance of adopting sustainable practices and alternative solutions such as bioethanol to reduce our overall carbon footprint. Together, even small changes can have a major positive impact on our planet. This clearly demonstrates that bioethanol, from renewable sources, has a considerable environmental advantage over traditional gasoline. The results obtained were graphically represented below:

Monitoring the evolution of PH during alcoholic fermentation

At the beginning of fermentation, the pH of the medium is usually slightly acidic, because the raw

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materials contain organic acids. This results in a lower pH value. As fermentation progresses, the yeast converts the sugars present in the raw materials into alcohol and carbon dioxide, also releasing acidic compounds. This results in a decrease in pH during the first hours of fermentation.

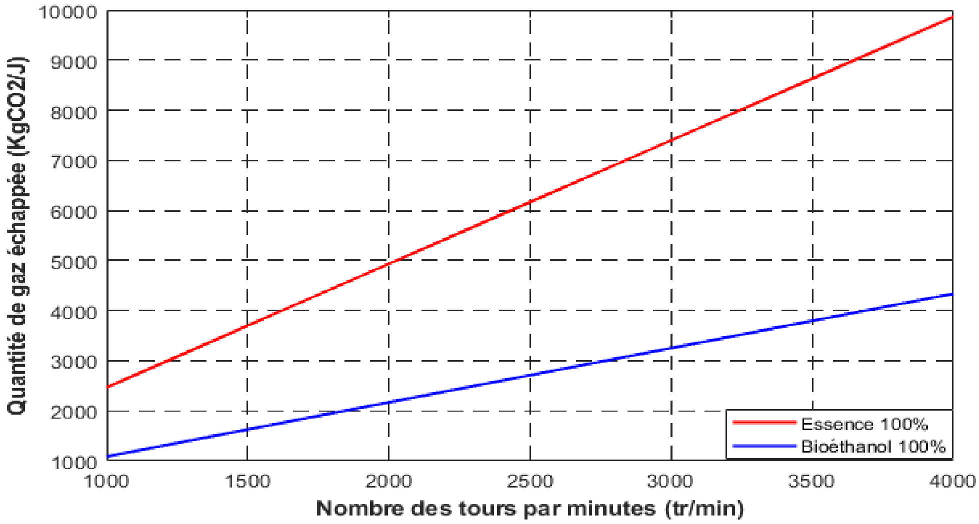

Figure 8. Amount of CO2 emissions during combustion of gasoline (100%) and bioethanol (100%)

Comparing the curve of the amount of CO2 released during the combustion of gasoline and bioethanol. We notice that the curve of gasoline shows a linear increase in the amount of CO2 released with the increase in the number of revolutions per minute. This suggests that the higher the engine speed, the more the amount of CO2 released increases proportionally. This is due to the combustion properties of gasoline and its chemical composition. On the other hand, the bioethanol curve shows an increase in the amount of CO2 released, less pronounced compared to gasoline, this attributed to the specific characteristics of bioethanol (calorific value and its oxygen content), which can influence combustion and reduce CO2 production.

In general, the combustion of bioethanol produces less CO2 than that of gasoline. This is partly due to the composition of bioethanol, which comes from renewable sources and also contains oxygen, which promotes more complete combustion and reduces CO2 emissions, whereas the composition of gasoline, which is mainly made up of hydrocarbons from petroleum, contributes to a higher production of CO2 during combustion.

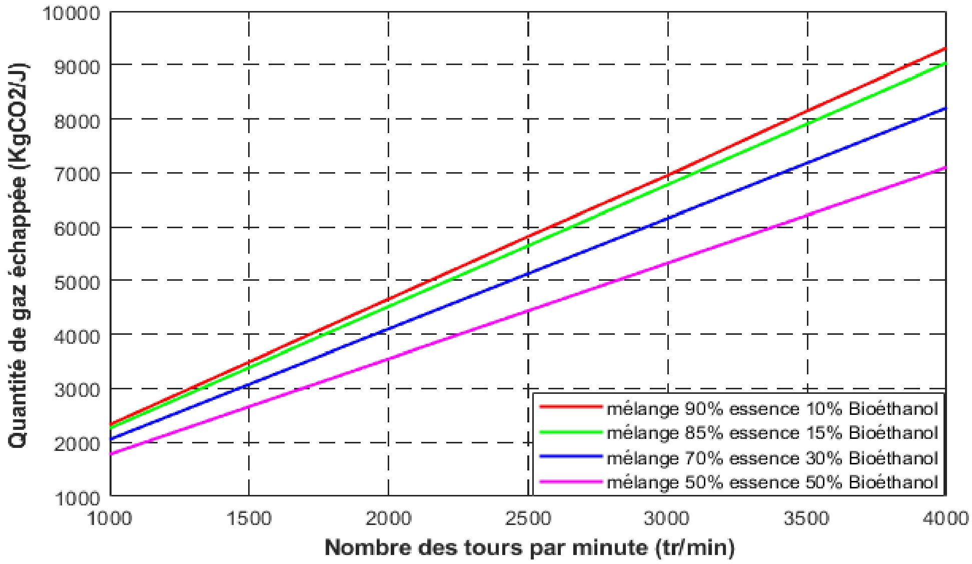

Figure 9. Curves of different bioethanol-gasoline blends

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We made blends of bioethanol and gasoline at different percentages (10%, 15%, 30% and 50%). We observed that the more we increased the proportion of bioethanol, the more the amount of CO2 emitted decreased. With a blend containing 10% bioethanol, we observed a slight reduction in emissions compared to pure gasoline, reaching 9100×10^{-13}KgCO2/J for an engine speed of 4000 rpm. However, when the proportion of bioethanol reached 50%, we recorded the greatest decrease in CO2 emissions. It was reduced to 7000×10^{-13}KgCO2/J for an engine speed of 4000 rpm. These results highlight the beneficial effect of using fuels containing bioethanol on reducing our carbon footprint, due to its renewable nature and low fossil carbon content.

IV. CONCLUSION

In conclusion, this study highlights the possibility of producing a sustainable and green fuel, bioethanol, from agricultural biomass substances (carob). The valuable advantage of bioethanol lies in its ability to reduce greenhouse gases in the environment compared to traditional gasoline.

Our study about the alcoholic fermentation and the comparative analysis of CO2 gas emissions between bioethanol, gasoline and their blends provided significant results. The observation of the fermentation parameters revealed an increasing alcohol production over time, thus confirming the proper progress of the process.

Regarding CO2 emissions, our results showed a progressive decrease in these emissions with the increase in the proportion of bioethanol in the fuel blends, it is also important to emphasize that although our carbon quantity results are minimal on an individual scale, they take on their full importance when cumulated by many cars. This highlights the significant impact that these small quantities can have on a large scale on CO2 emissions and therefore on the environment. This finding reinforces the importance of adopting sustainable practices and alternative solutions such as bioethanol to reduce our overall carbon footprint. Together, even small changes can have a major positive impact on our planet. This clearly demonstrates that bioethanol, derived from renewable sources, has a considerable environmental advantage over traditional gasoline.

Finally, it is crucial to continue supporting research and development of sustainable fuels such as bioethanol, as well as promoting fuel blends to reduce CO2 emissions. This approach, combined with appropriate policies and incentives, can make a significant contribution to reducing our carbon footprint and building a cleaner and more sustainable future for transport

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