COMPARATIVE STUDY OF THE YELD ACCORDING TO THE OPERATING CONDITIONS OF THE PYROLYSIS OF PLASTIC FILM WASTE FROM FOOD PACKAGING

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ABSTRACT

Pyrolysis is a thermochemical decomposition of an organic material at high temperature and in the absence of oxygen, making it possible to obtain three main products obtained: a mixture of non-condensable light gases, a mixture of hydrocarbons in liquid and the solid residue named coal. The study at the laboratory scale of the mass yield of the products of the pyrolysis of food packaging waste in plastic films shows that the proportion of each fraction depends on the nature of the plastic film waste, as well as on the process conditions on the evolution of the temperature as a function of time and the final temperature. The results obtained lead us to evaluate that the presence of metal compounds in the waste films constitutes a catalyst which disadvantages the production of pyrolytic oil allowing the majority of non-condensable gases to be obtained, i.e., 88% in maximum value, while those not metallics give 62% better oil yield. The difference in the yield of the solid residue between transparent film waste (3% to 4%) and printed-metallized film waste (7% to 9%) highlight the mineral materials resulting from coloring and printing inks as well as the compounds metallic.

Keyword: *pyrolysis, plastic film waste, pyrolytic oil, non-condensable gases, coke.*

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1. INTRODUCTION

Currently plastics occupy the majority of packaging sectors. In general, food packaging accounts for 36% of the global production of plastics, half of which is for single use. Very light and bulky, their waste is distributed quickly in nature, causing adverse effects on the environment and human life. At present, various industries are recovering plastic packaging waste. Some are embarking on material recovery in which this waste is re-extruded and re-transformed into new usable materials. In addition, many industries practice energy recovery based on incineration while recovering usable energy. Others are devoted to chemical recovery, which involves returning plastic waste to the starting monomers or petrochemical products [1].
Among the recovery methods, this study is focused on chemical recovery by pyrolysis, which is a process for the thermo-chemical conversion of primary packaging food waste into plastic film, in the absence of oxygen to produce three distinct phases: liquids, solids and gases. The aim of this study is to determine the operational conditions leading to the best yield in liquid or gas from the pyrolysis of plastic film waste [2].

2. MATERIALS AND METHODS

2.1 The materials

We have to use different materials:

- Precision balance
- Volumetric fuel oil or graduated cylinder
- Thermocouple
- Raw materials: plastic film waste from primary packaging. Four categories of film waste were highlighted, such as mixed film waste, metallized film waste, non-metallized film waste and transparent film waste.

  For each four categories of film waste, it represents one on by one by:
  - Fig -1: Mixed film waste
  - Fig -2: Metallized film waste
  - Fig -3: Non-metallized film waste
  - Fig -4: Waste films without coloring

Fig -1: Mixed film waste

Fig -2: Metallized film waste

Fig -3: Non-metallized film waste

Fig -4: Waste films without coloring

- The pyrolizer

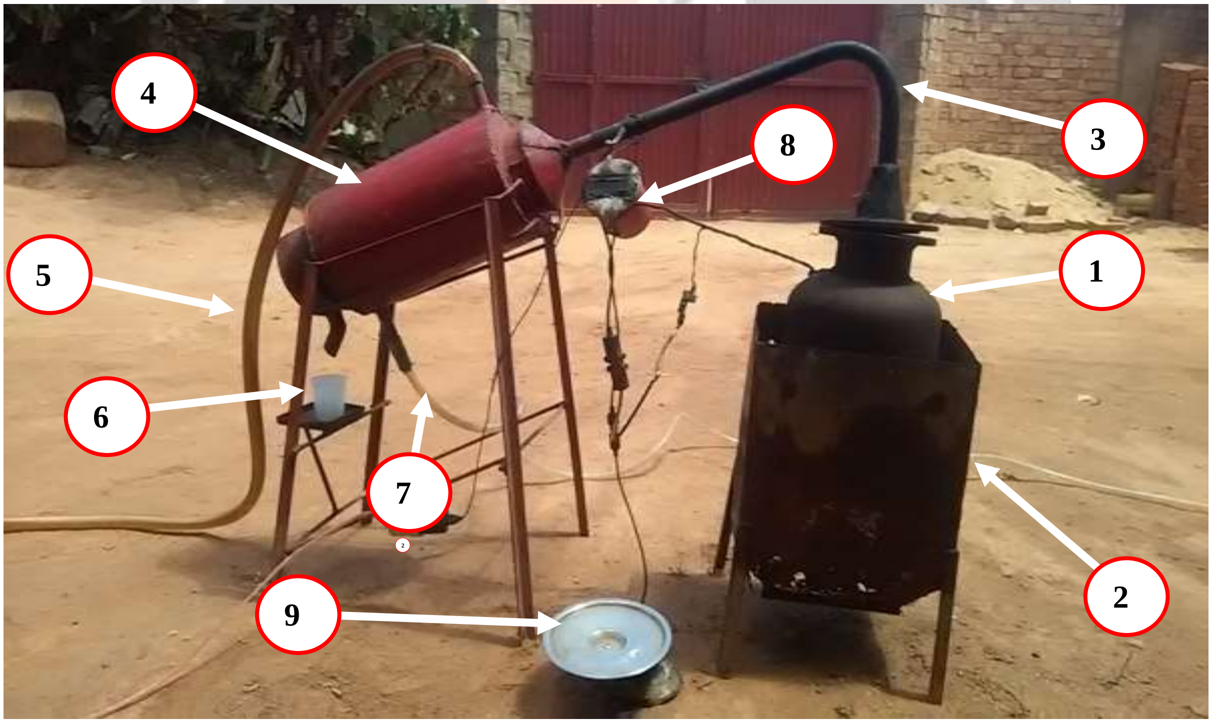

Fig -5: Waste films without coloring

1: The reactor	2: The hearth	3: The Gas line
4: The condenser	5: The water inlet pipe	6: The condensate
7: The water outlet pipe	8: The thermocouple	9: The precision balance

The hearth is the place of heating supply, the reactor is used to charge the raw material and discharge the solid residue after pyrolysis, the pipe is the channel through which the gases from the heating are led to the condenser. The condenser provides heat exchange between the refrigerant and the gas to recover the condensable fraction.

2.2 Methods

The method is divided into three steps:

- **Preparation phase**

This step consists of preparing the raw materials and materials to be used. Then, the waste films to be pyrolyzed must be weighed before being inserted into the reactor. Finally, you have to install the device.

- **Pyrolysis process**

The Pyrolysis consists of a degradation, or cracking, of polymer molecules subjected to a high temperature (between 300° C and 600 ° C) to obtain smaller molecules [1].
First, you have to start the heating in the hearth in order to heat the waste to be pyrolyzed in the reactor. The thermocouple allows you to know the evolution of the temperature during heating. As the temperature increases, the cracking reaction is favored, in which the molecules degrade while producing gas which will pass through the pipe to the condenser.
During condensation, the gases are cooled by water from the Jirama (It's the filial of the state of Madagascar which buy Water and electricity for the people) to room temperature, hence the need for the water inlet and outlet pipe in the condenser. In the presence of non-condensable gases, the condensation is not complete and a quantity of vapor will be evacuated in gaseous form at the outlet of the condenser; while the condensed gases turn into oil which is collected in a beaker.
When no more oil is produced, the heating is stopped and the reactor is cooled, the pyrolysis reaction is said to be coming to an end [2].

- **Study of the mass yield of finished products**

At each pyrolysis, the solid residues remaining in the reactor after cooling must be recovered. The oil obtained as well as the solid residues are weighed subsequently, in order to be able to study the mass yields of the finished products during pyrolysis.
The mass fraction yields of the pyrolysis products were calculated by the following formulas:

$$\eta_l = \frac{m_l}{m_{DCF}} \times 100 \quad (1)$$

$$\eta_s = \frac{m_{rs}}{m_{DCF}} \times 100 \quad (2)$$

$$\eta_g = \frac{m_{DCF} - (m_l + m_{rs})}{m_{DCF}} \times 100 \quad (3)$$

Where: η_l , η_s , η_g are the yields of liquid, solid and gaseous fractions of pyrolysis products and m_{DCF} , m_{rs} , m_l represent the mass of waste films to be pyrolyzed, the mass of solid residue and respectively the mass of the pyrolysis liquid.

3. RESULTS AND DISCUSSION

3.1 Mass yield of finished products:

The study is based on the pyrolysis process by identifying the influence of the yield or mass fraction of finished products, depending on the types of plastic waste. The experiments were carried out with four types of film waste tests such as mixed film waste, metallized film waste, non-metallized film waste and non-coloring film waste.

- **Mixed film waste:**

Table -1: Pyrolysis yield of the film waste mixture

Mass (g)	Yield %		
	Oil	Solid residue	Gas
985	24,56	27,25	48,18
950	37,66	6,75	55,58
400	39,51	8,46	52,03
400	11,25	5,50	83,25

In view of these results, it is remarkable that the pyrolysis of the waste films results in a low yield of pyrolytic oil and it favorably produces non-condensable gases. In fact, the highlighted film waste is characterized by a strong presence of printing inks and dyes as well as metallic layers. By the hypothesis, the additional fillers and the metallic layers can constitute catalysts to reinforce the gaseous products during pyrolysis. Thus, to confirm this hypothesis, it is necessary to proceed with the pyrolysis of the metallized film waste, then the non-metallized waste and finally the discolored film waste.

- **Metallized film waste:**

Waste metallized films are characterized by the complex films having a metallic layer. The study of the pyrolysis of these types of film waste allows us to verify the influence of the presence of metals on the quantity of finished products.

Various tests were carried out, the results of which on their yields are:

Table -2: Pyrolysis yield of metallized film waste

Mass (g)	Yield %		
	Oil	Solid residue	Gas
800	24,53	11,42	64,05
800	19,63	7,36	73,01
400	23,25	6,25	70,5
400	30	5,75	64,25
400	6	6	88

These results on various tests show that the production of non-condensable gases is very favorable during the pyrolysis of the metallized film waste. It can be deduced from this that the presence of metal layers in the waste films promotes the excessive production of non-condensable gases during pyrolysis. This results in very little pyrolytic oil as well as solid residues. Therefore, the metal layers can act as a catalyst to exceptionally form gaseous products during pyrolysis. Thus, it remains to know the result of the pyrolysis in the absence of the metal layers, in particular the waste films containing only the printing inks and dyes.

- **Non-metallized film waste:**

It is a film waste that contains only printing inks and dyes without any trace of metallic layers. The study of the pyrolysis of these waste films highlights the influence of the finished products on the absence of metals in the process. therefore, these are the yield of pyrolytic oil, of solid residues as well as the non-condensable gases of each test of the pyrolysis of non-metallized film waste:

Table -3: Pyrolysis yield of non-metallized film waste

Mass (g)	Yield %		
	Oil	Solid residue	Gas
400	32	28,75	39,25
800	61,96	9,80	28,24
800	60,86	8,95	30,19
800	40,7	6,93	52,37
400	53,75	7,5	38,75

In particular, the pyrolysis of non-metallized film waste achieves a better pyrolytic oil yield. In fact, these tests make it possible to verify that the printing inks and dyes are not the major factors in the massive production of non-condensable gases during the pyrolysis of waste films. To determine the influence of the presence of printing inks and dyes on the pyrolytic oil yield, it is necessary to pyrolyze the waste films without coloring.

- **Transparent film waste:**

This pyrolysis is intended to analyze the effect of the absence of metals, printing inks and dyes on the yield of the products obtained.

Table -4: Pyrolysis yield of transparent film waste

Mass (g)	Yield %		
	Oil	Solid residue	Gas
600	38,36	2,8	58,80
400	40,12	2,75	57,13
800	61,57	3,20	35,23
800	70,15	3,47	26,38

The yield of the products obtained during the pyrolysis of the transparent film waste shows that the pure polymers provide a yield of 70% of pyrolytic oil. In addition, the elimination of dyes and printing inks as well as the metallic layers in the waste films reduces the amount of mineral matter in the discolored film waste, hence the reduction in solid residues during pyrolysis.

In view of these results, the pyrolytic oil yield of the pyrolysis of the non-metallized film waste and that of the discolored film waste are approximately similar. Which shows that the presence of printing inks and dyes in the waste films generally has no effect on the production of non-condensable gases during pyrolysis. This study therefore affirms that it is the metal compounds which behave as a catalyst to produce non-condensable gases at room temperature during the pyrolysis of waste films.

3.2 Heating speed

- **The pyrolytic oil:**

This temperature changes as a function of time shows that, the more the temperature increases, the more the pyrolytic oil yield increases. Especially in the presence of metal in the films waste, when the heating rate is so fast, in other words, fast pyrolysis, the cracking reaction for the formation of molecules with carbon chains greater than 4 is therefore favored if the pyrolysis reaches its end at 400 ° C in approximately 60 minutes.

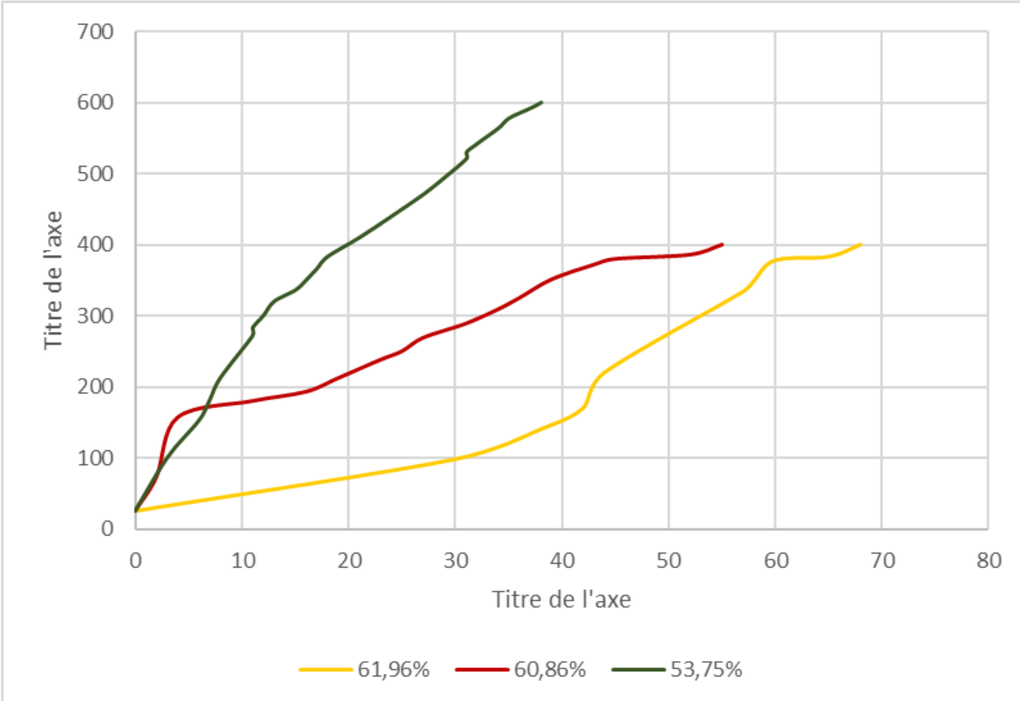

Fig -6: Evolution of the temperature corresponding to the major obtaining of oil

- **The non-condensable Gas :**

The condition of the temperature changes to provide good gas yield during this study:

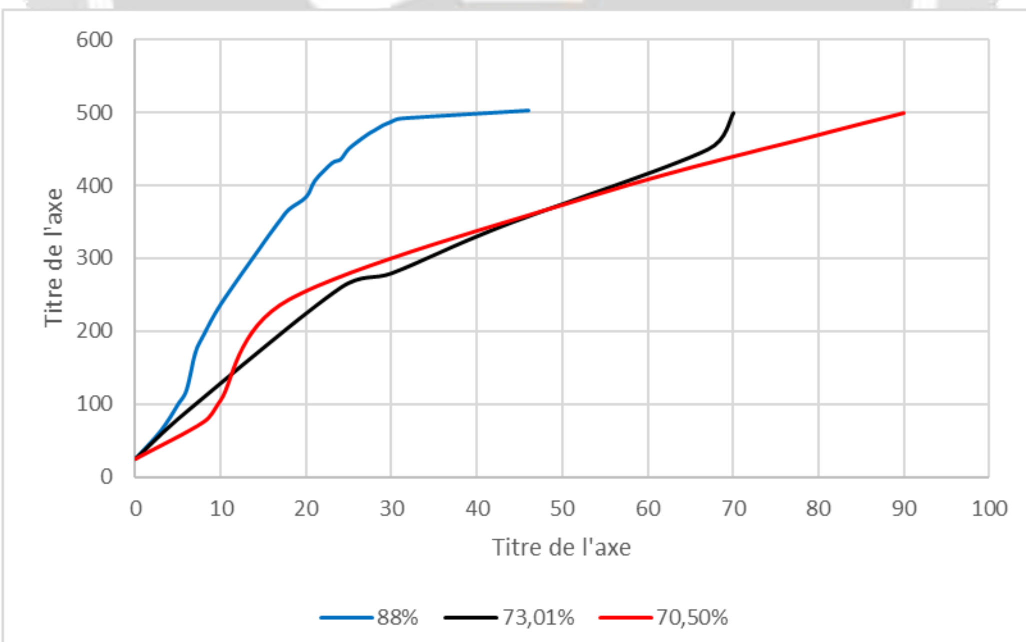

Fig -7: Evolution of temperature following the obtained gas

This curve allows us to deduce that the faster the rise in temperature during pyrolysis, the more the production of non-condensable gases is favored.
In addition, the final reaction temperature should not be below 500 ° C in which the residence time of pyrolysis should be very short of the order of 40 minutes. So, the non-metallized film doesn't product gases in this pyrolysis when the reaction was so fast.

3.3 Valuation of finished products

The table below summarizes the results obtained throughout this study as well as the appearance of the liquid resulting from condensation during pyrolysis:

Table -5: Summary of the pyrolysis yield from plastic film waste

Waste films	Mass yield (%)			Oil Appearance
	Liquid	Solid	Gas	
Mixing	38-43	7-9	48-83	Liquid / gel
Metallized	6-30	6-7	65-85	Liquid / gel
Non-metallized	40-60	7-9	30-50	Liquid / gel
Transparent	40-60	3-4	30-50	Liquid / gel

Whether it is « pyrolysis of more or less mixed plastic waste » or « pyrolysis of specific film waste », pyrolysis leads to the production of three distinct fractions, the proportions of which vary according to the nature of the waste used:

- An oil: which can be reprocessed and refined in order to obtain a petrochemical base of the naphtha type or more generally polyolefins with C5-C10 chains, which can also be energetically upgraded on the fuel production site. High calorific liquid, that could be used in internal combustion engines to generate electricity and heat. However, the resulting oil turns partially or completely into a gel. In this case, it requires heating to temporarily revert to liquid. If not, the gel can be used directly as a wax [3] [4].

- A gas: which is a gas mixture of CO, H_2, CH_4, C_nH_p ($n < 4$). Most often, this gas is burned on site to provide the energy necessary for the pyrolysis reaction and possible drying of the incoming feed. After purification, this gas can be used directly in gas engines or gas turbines. Another light gas can be used as a monomer and as a raw material for petrochemicals. After separation of this gas mixture, hydrogen is well known as a carrier gas and fuel gas for gas chromatography [3] [5].

- A solid by-product called pyrolysis coke: made up of fixed carbon which does not react during a cracking reaction, and the incombustible fraction of the treated film waste. Transparent film waste, which has a minimal coke yield, shows that colored and metallized film waste contains minerals from dyes and pigments in printing inks and also metal compounds. This coke can either be burned to provide the thermal input necessary for pyrolysis (pyro-gasification), or used as a secondary fuel, or gasified in a separate device, after purification, or transformed into activated carbon widely used in water treatment [3] [6].

4. CONCLUSION

In this study, the pyrolysis of mixing of food packaging waste into plastic films gave a maximum of 39,51% in liquid and 83,25% in gas. But the metallized food packaging film waste promotes the major production of short carbon chain gases with a maximum yield of 88% at 600 ° C in a very fast heating rate, while those not metallized and transparent allow to obtain respectively 61,96% and 61,26% of liquids with long carbon chains with a fairly rapid heating rate up to 350 and 400 ℃. We therefore deduce that the presence of metal compounds in the waste films constitute a catalyst that hinders the production of long-chain carbon chains (n> 4) and thus maximizes the yield of non-condensable gas (n <4) during pyrolysis, especially if it done quickly. Thus, to recover most of the pyrolytic oil, it is advisable to proceed with a slow pyrolysis at a temperature between 350 and 400°C and it is important to remove the metal compounds in the process. Finally, the coke containing the mineral fraction of the film waste, and the remaining carbon, generally varies from 6 to 9% for colored or metallized film waste, while a yield of 3 to 4% is observed for transparent film waste, this which marks the presence of minerals in dyes and printing inks as well as metallic compounds.

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