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Pyrolysis of Discarded Chewing Gum for Acetic Acid Recovery

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Abstract

Chewing gum, typically discarded indiscriminately, is a significant source of urban solid waste with waste that persist for long period. When in contact with notoriously recyclable materials, it can hinder their recycling processes due to its high post-consumer adhesion, leaving only the non-soluble phase. This gum base is commonly composed of polyvinyl acetate (PVAc). In this context, considering what is done for the recycling of other polymers, the pyrolysis of discarded chewing gum was conducted through a series of reactions to produce bio-oil. The influence of temperature, time, and pressure was studied to find the conditions that would favor the highest production of the liquid phase. The results demonstrated that temperature, reaction time, and pressure significantly influenced product distribution. The highest bio-oil yield was obtained at 350°C for 60 min, producing 2.20 g and 1.64 g of bio-oil at initial pressures of 15 and 70 bar, respectively. GC-MS analysis revealed acetic acid as the predominant compound, reaching a maximum concentration of 94.6% at 300°C for 40 min and 15 bar, while acetaldehyde was detected only under low-pressure conditions. These findings demonstrate the feasibility of converting discarded chewing gum into value-added chemicals through pyrolysis.

Keywords
Discarded chewing gum; pyrolysis; recycling; bio-oil; acetic acid and ethanoic acid

1. Introduction

Chewing gum is a non-food item produced from gum base, which consists mainly of synthetic elastomers: polyvinyl acetate, styrene-butadiene copolymer, and polyisobutylene, with the addition of emulsifiers, colorants, and sugars. Two phases are present in the formulation: the first is a water-insoluble phase, composed of the non-digestible polymer, while the second, formed by the edible substances, is soluble. After use, chewing gum, due to specific interfacial forces, becomes strongly adherent to various surfaces, leaving behind only the first phase mentioned above [1, 2].

The disposal of this material is a significant urban problem: approximately 1.74 trillion pieces of chewing gum are produced worldwide each year [3]. As a result, chewing gum is the second most common type of urban waste, second only to cigarette butts. It is worth noting that Brazil is the second-largest producer and consumer of chewing gum in the world. In addition, widely sold chewing gum is non-biodegradable and remains in the environment for at least five years; it is also recognized as a carrier of bacteria and viruses that cause diseases transmitted through saliva. According to information from Get Green Now, a website dedicated to sustainable initiatives, millions of dollars are spent every year to clean streets and avenues of chewing gum stuck to the ground: In England, discarded chewing gum has been reported as one of the most common forms of litter found on pavements [3].

Pyrolysis has been widely investigated as an alternative treating of polymeric residues that are difficult to recycle by conventional methods. The process converts waste into liquid, gaseous, and solid fractions that can be used as fuels, chemical feedstocks, or carbon-rich materials. Recent studies have shown that advances in catalyst development and process control can improve product selectivity and conversion efficiency, expanding the range of applications for pyrolysis in waste management and resource recovery [4, 5].

Recent research has also focused on obtaining specific chemical compounds from plastic waste rather than exclusively targeting fuel production. This approach can increase the value of the recovered products and broaden the industrial use of pyrolysis-derived materials. Since discarded chewing gum contains a gum base largely composed of polyvinyl acetate, its thermal degradation may yield oxygenated compounds such as acetic acid, a chemical widely used in industrial processes and in the manufacture of vinyl acetate [5, 6].

Studies on the pyrolysis of polyethylene, polypropylene, polystyrene, and mixed plastic wastes are widely available in the literature [1-3, 7, 8]. In contrast, few studies have examined the thermal conversion of discarded chewing gum. Previous investigations involving this residue have focused mainly on its application in asphalt modification, hydrogen production, and composite materials [9-11]. Data relating operating conditions to product distribution and bio-oil composition are not commonly reported for discarded chewing gum. The present work investigates the influence of temperature, reaction time, and pressure on the pyrolysis of this residue and the composition of the products obtained [11].

In light of the above, solutions for recycling chewing gum have grown substantially in recent years. Recent studies have identified this previously discarded material as an economically viable additive for asphalt, imparting greater durability and heat resistance, as well as other valuable properties. In 2018, biohydrogen was successfully produced from waste from the chewing gum industry using a two-stage hybrid fermentation system. In Brazil, discarded chewing gum was used as a matrix for quartz crystals. A composite was formed that can be used as a pressure-measuring element, which is widely employed in control systems for the chemical industry [3, 4, 12].

Despite this, as with notoriously recyclable materials, there is a huge challenge in collecting and sorting chewing gum. The lack of public consensus regarding the proper disposal of chewing gum, whether in organic or recyclable waste, makes it impossible, due to its high degree of stickiness, not only to recycle the gum itself but also other materials of different types, which, when properly separated, have the full potential to reintegrate into a circular economy [5, 6-13].

Therefore, the need to consider the recycling of materials without clearly defined uses makes discarded chewing gum a waste product with untapped potential. Particularly in Brazil, where consumption is massive yet collection and recycling of this material are minimal, it is imperative to study techniques that enable its reintegration into useful applications [8]. Thus, the analysis conducted in this study focuses on the feasibility of bio-oil production, using hard-to-recycle materials, specifically discarded chewing gum, as the starting point. For this purpose, pyrolysis, a thermal degradation process carried out in the presence of low concentrations of oxygen or in an oxygen-free environment, is deemed appropriate [9, 14, 15]. This method is widely used for the same purpose with large-scale polymers such as polypropylene, polystyrene, and polyethylene. To elucidate the optimal conditions necessary for converting the sample into a higher liquid phase fraction, a series of reactions was conducted in a batch reactor. The pyrolysis of discarded chewing gum has proven to be a viable method for producing acetic acid, which is used in the production of the primary polymer in gum base, thereby enabling integration into a circular economy, as well as acetaldehyde, which is widely used, for example, in the production of acetic acid [16, 17].

2. Materials and Methods

2.1 Reaction Parameters

The discarded chewing gum was collected from trash cans placed by the project author on the Darcy Ribeiro Campus at the University of Brasília and, as such, varied in size, color, and brand. Furthermore, it is important to note the possibility that other contaminants, such as saliva and food debris, may be present in the samples.

The reactions were conducted in a batch reactor equipped with a thermowell and a pressure gauge for measuring temperature and pressure, respectively. A countercurrent heat exchanger was connected to the reactor, through which water at room temperature flowed to condense the pyrolysis products. Before the reactions began, the reactor was pressurized with nitrogen gas to ensure an inert atmosphere. The reactions were conducted at initial pressures of 15 bar and 70 bar. Using a power regulator, a heating jacket was employed to reach temperatures of 300°C, 325°C, and 350°C, as measured by a contact thermometer inserted into the thermowell with access to the reactor interior, at different time points: 10 min, 20 min, 40 min, 60 min, and 120 min.

The temperature range of 300-350°C was selected based on studies describing the thermal degradation of polyvinyl acetate and plastic residues [10-18]. Within this range, deacetylation

reactions occur, and liquid and gaseous products are formed. The reaction times (10 min to 120 min) were used to monitor product formation after the target temperature had been reached [18, 19].

Initial pressures of 15 and 70 bar were adopted to examine the effect of pressure on product distribution. A mass of 10 g was used in all experiments and kept constant throughout the study [20]. This mass corresponded to the amount used in each reactor batch and allowed the results obtained under different conditions to be compared. All batches were prepared using 10 g samples [21, 22].

A countercurrent condenser cooled with room-temperature water was connected to the reactor. During pyrolysis, the condensable products were collected as the liquid fraction (bio-oil). After each experiment, the masses of the liquid and solid fractions were determined gravimetrically. The gaseous products were not collected during the experiments. Therefore, the gas fraction was estimated by mass balance from the difference between the initial mass of chewing gum and the masses of bio-oil and solid residue recovered after the reaction. The gas fraction was calculated according to Equation 1:

$$Gas(g) = Initial\ sample\ mass - (bio\text{-}oil\ mass + solid\ residue\ mass) \quad (\text{Eq. } 1)$$

Therefore, the values reported for the gaseous fraction correspond to the estimated mass of non-condensable products generated during pyrolysis.

The reactor was equipped with a pressure gauge and a thermowell connected to a contact thermometer for monitoring pressure and temperature during the experiments. Heating was supplied by an electric heating mantle controlled by a power regulator. Before each reaction, nitrogen was introduced into the reactor, and the system was sealed. The experiments were carried out at temperatures ranging from 300 to 350°C, reaction times from 10 to 120 min, and initial pressures of 15 and 70 bar.

2.2 Characterization of Bio-Oil

After the reactions, the amounts of solid (biochar) and bio-oil collected in the reactor was measured, and the mass of gas produced during the procedures was thus approximately calculated. Using Fourier transform infrared spectroscopy (FTIR), the organic functional groups present in the liquid phase were identified. Subsequently, the chemical composition of the bio-oil was confirmed by gas chromatography-mass spectrometry (GC-MS), using isopropanol as the solvent.

Before GC-MS analysis, the bio-oil samples were diluted using isopropanol as an internal standard. Compound identification was performed by comparing mass spectra with the mass spectral library, using a minimum similarity index (SI) of 85. The concentrations of acetic acid and acetaldehyde were calculated from the chromatographic response relative to the internal standard.

3. Results and Discussion

3.1 Minimum Point

Since the collected chewing gums could have different formulations, as explained earlier, it was first necessary to determine the minimum temperature and residence time for thermal degradation to yield a measurable amount of bio-oil [23-25]. Consequently, the following minimum condition for cracking was observed: after 20 min of reaction at a temperature of 300°C and an initial pressure

of 70 bar, 1.09 g of bio-oil were generated. Consequently, based on mass balance, it is inferred that approximately 0.59 g of gas was generated. At the same temperature, reactions that occurred over shorter times resulted only in a solid fraction.

3.2 Influence of Temperature

To evaluate the influence of temperature on product distribution, the masses obtained from pyrolysis were compared after 1 h at each selected temperature. In slow pyrolysis conducted in a batch reactor, the residence time is the period from when the sample, once in the reactor, begins heating until its removal from the reaction medium.

Heating increases the vibrational state of chemical bonds. Thus, when the energy of these bonds becomes sufficiently high, homolytic cleavage occurs, leading to the formation of smaller radical species. For this reason, as shown in Table 1, when time is constant, an increase in temperature favors greater conversion of the sample into bio-oil and gas [19, 26]. Consequently, longer heating periods were required to reach higher temperatures, as shown in Table 1 [27, 28].

Table 1 Mass distribution of the products at different temperatures, with an initial pressure of 70 bar.

Time (min)	Temperature (°C)	Solid (g)	Biofuel (g)	Gas (g)
	300	7.69	0.08	2.23
60	325	7.15	0.23	2.62
	350	5.21	1.64	3.15

The reduction in the solid fraction from 7.69 g at 300°C to 5.21 g at 350°C was accompanied by an increase in bio-oil and gas production. Polyvinyl acetate undergoes deacetylation between 300 and 400°C, releasing acetic acid and forming unsaturated structures in the remaining polymer chain [29, 30]. The higher conversion observed at 350°C is in agreement with this degradation range. Gas production increased from 2.23 g to 3.15 g between 300 and 350°C [31, 32].

3.3 Influence of Time

The time to be considered is the period elapsed after reaching the desired temperature, which differs from the residence time. The temperatures chosen for the analysis of this parameter were 300°C and 350°C, as they yielded significant amounts of bio-oil. For the latter, a 2 h reaction was conducted to complement the analysis of phase distribution. The objective was to identify the point at which the formation of non-condensable gases predominates over the generation of the liquid phase, as shown in Table 2 [2, 11, 23-33]:

Table 2 Mass distribution of the products at a temperature of 300°C and an initial pressure of 70 bar.

Temperature (°C)	Time (min)	Solid (g)	Bio-oil (g)	Gas (g)
	20	8.32	1.09	0.59
300	40	7.52	0.51	1.97
	60	7.39	0.08	2.53

At 300°C, bio-oil production decreased from 1.09 g after 20 min to 0.08 g after 60 min, while gas production increased from 0.59 g to 2.53 g. This change in product distribution shows that part of the liquid fraction formed during the initial stages of pyrolysis was converted into gaseous products as the reaction proceeded [33, 34].

The table showing the reactions conducted at 300°C reveals an inversely proportional relationship between the elapsed time after reaching the target temperature and bio-oil production. In contrast, gas generation is promoted by this same parameter. Therefore, it can be inferred that, following bio-oil production, part of the liquid fraction evaporates, forming non-condensable gases [24, 25, 34].

At 350°C, bio-oil production reached 1.64 g after 60 min and decreased to 0.22 g after 120 min. During the same period, gas production increased from 3.15 g to 5.54 g. These results show a progressive conversion of condensable products into gaseous compounds at longer reaction times [2, 35, 36]. However, an inflection point is evident: an indefinite increase in the pyrolysis time can reduce the amount of bio-oil generated, thereby favoring gas formation (Table 3). This effect is recognized for reactions at higher temperatures [37, 38].

Table 3 Mass distribution of the products at a temperature of 350°C and an initial pressure of 70 bar.

Temperature (°C)	Time (min)	Solid (g)	Bio-oil (g)	Gas (g)
350	20	6.86	0.61	2.53
	40	6.28	0.74	2.98
	60	5.21	1.64	3.15
	120	4.24	0.22	5.54

3.4 The Effect of Pressure

The reactions, previously conducted at an initial pressure of 70 bar, were repeated with the reactor pressurized to 15 bar to analyze the influence of this variable on the formation of the liquid phase and the distribution of products. In both pyrolysis runs, the pressure increased, reaching 100 bar and 45 bar, respectively (Table 4, Table 5, and Table 6). This demonstrates both the proportional relationship between the increase in temperature and pressure in the reactor—which can be considered a constant-volume system—and gas production [36-38]. Differences were also observed in the composition of the liquid fraction. Acetaldehyde was detected only in experiments carried out at 15 bar, while acetic acid was identified under both pressure conditions. The lower boiling point of acetaldehyde may explain its occurrence in the products obtained at lower pressure [39, 40].

Table 4 Mass distribution of the products at different temperatures and an initial pressure of 15 bar.

Time (min)	Temperature (°C)	Solid (g)	Bio-oil (g)	Gas (g)
60	300	8.24	0	1.76
	325	7.68	0	2.29
	350	3.32	2.20	4.48

Table 5 Mass distribution of the products at a temperature of 300°C and an initial pressure of 15 bar.

Temperature (°C)	Time (min)	Solid (g)	Bio-oil (g)	Gas (g)
300	20	8.64	0	1.36
	40	5.85	0.30	3.85
	60	8.24	0	1.76

Table 6 Mass distribution of the products at a temperature of 350°C and an initial pressure of 15 bar.

Temperature (°C)	Time (min)	Solid (g)	Bio-oil (g)	Gas (g)
350	20	7.08	0	2.92
	40	4.78	1.15	4.07
	60	3.32	2.20	4.48
	120	2.73	0.75	6.52

Under these conditions, the following minimum cracking conditions were observed: a reaction temperature of 300°C and a reaction time of 40 min, which yielded 0.30 g of bio-oil. Evidently, at lower pressures, thermal degradation took longer. Again, increasing the temperature resulted in greater conversion of the sample into bio-oil and gas. When compared to reactions at different temperatures for the same duration (60 min) conducted at an initial pressure of 70 bar [41, 42].

Those reactions conducted at an initial pressure of 15 bar demonstrated higher bio-oil conversion only at the higher temperature (350°C). This phenomenon can be explained for most polymers, since, at high pressure, the production of these two phases predominates, although such effects are apparent only at high temperatures [43, 44].

As before, the optimal time for bio-oil generation at the highest temperature was 60 min. At 120 min, the amount of liquid phase dropped significantly, as did the amount of cracked solid, thus illustrating the predominance of non-condensable gas formation at longer reaction times. It is also noted that the reactions that did not yield a significant and, consequently, measurable amount of bio-oil were, however, moist [45, 46].

3.5 Chemical Composition of Bio-Oil

3.5.1 FTIR

Using Fourier transform spectroscopy on the samples that produced bio-oil at a pressure of 15 bar, the following graph was obtained, as shown in Figure 1 [17]:

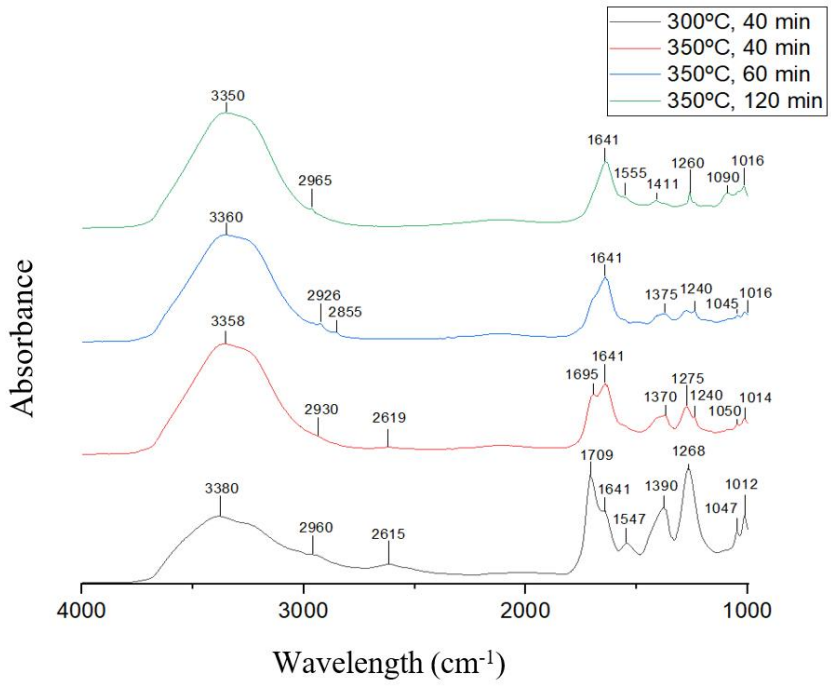

Figure 1 FTIR spectrum of the bio-oil obtained from reactions conducted at 15 bar.

For the reactions conducted 70 bar, shifts and band formation were observed (Figure 2, Figure 3 and Figure 4), which will be explained below [17].

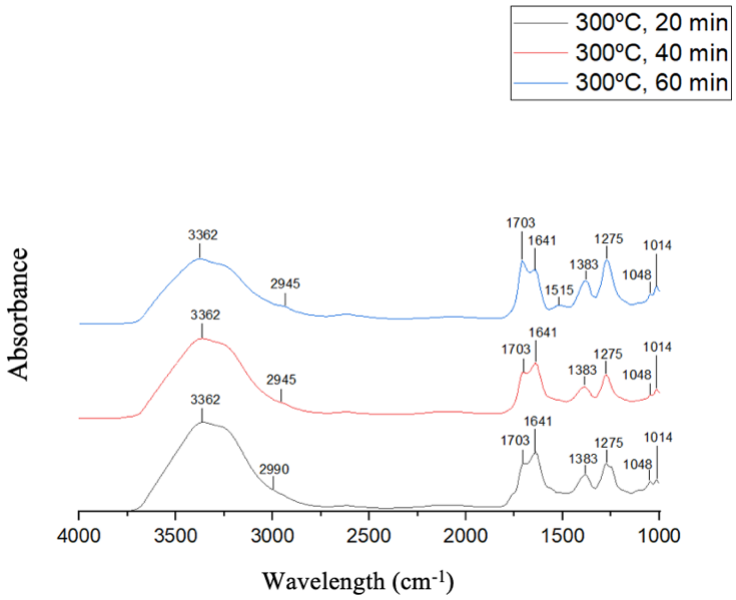

Figure 2 FTIR spectrum of the bio-oil obtained from reactions conducted at 300°C and 70 bar.

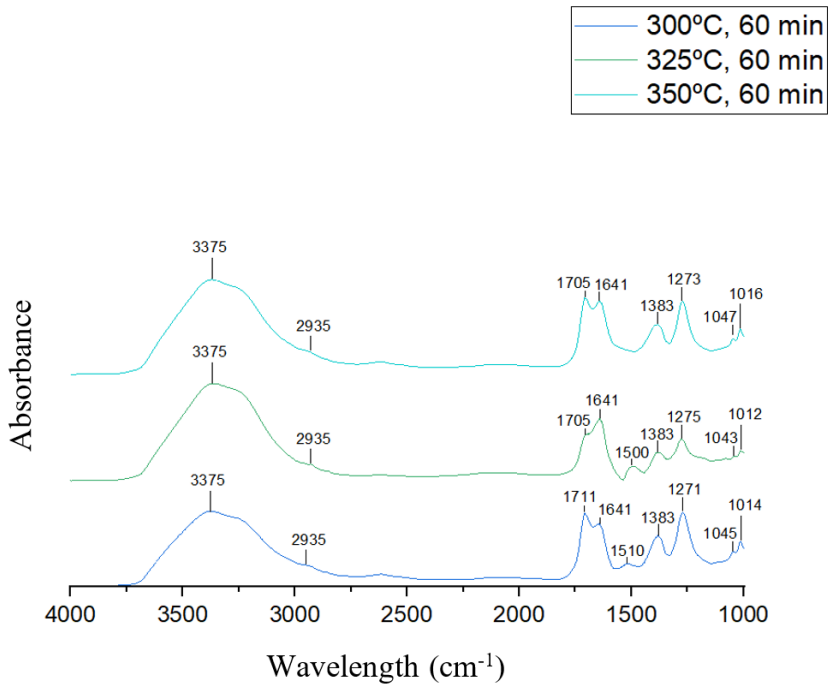

Figure 3 FTIR spectrum of the bio-oil obtained from reactions conducted at different temperatures at 70 bar.

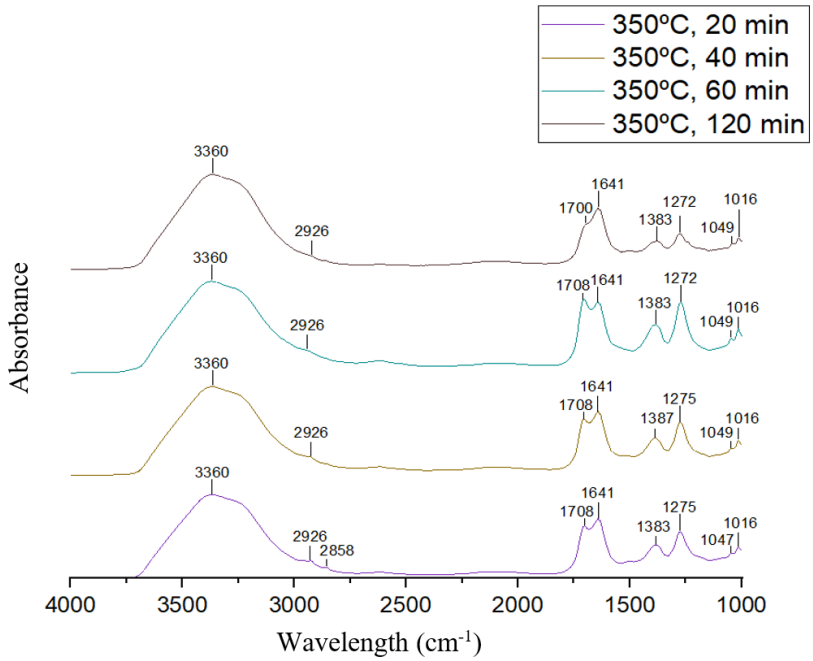

Figure 4 FTIR spectrum of the bio-oil obtained from reactions conducted at 350°C and 70 bar.

The spectra (Figure 2, Figure 3 and Figure 4) show, primarily, characteristic peaks of the hydroxyl (OH) group, as well as methyl (C-H) stretching and the presence of the carbonyl (C=O) group. Increases in temperature, time, and pressure appear to have minimal effects on the distribution of identifiable groups present in the bio-oil [17, 42]. The absorption bands observed in the FTIR spectra were assigned according to the literature and are summarized in Table 7.

Table 7 FTIR band assignments for the bio-oil samples.

Wavelength (cm^{-1})	Band	Functional group
3360-3375	O–H stretching	Carboxylic acids
2926-2950	C–H stretching	Aliphatic CH_3 groups
1700-1711	C=O stretching	Carboxylic acids
1641	C=C stretching	Unsaturated structures
1383-1387	CH_3 bending	Methyl groups
1271-1275	C–O stretching	Carboxylic acids and esters
1047-1056	C–O stretching	Oxygenated compounds

The absorption band at 3360-3375 cm^{-1} is attributed to O–H stretching of carboxylic acids. The band observed between 1700 and 1711 cm^{-1} is characteristic of C=O stretching and is consistent with the presence of carboxylic acids identified by GC-MS. The signal at 1641 cm^{-1} is attributed to C=C stretching of unsaturated structures formed after deacetylation of polyvinyl acetate. Bands in the regions 1271-1275 cm^{-1} and 1047-1056 cm^{-1} are related to C–O stretching vibrations, while the absorptions at 1383-1387 cm^{-1} are attributed to CH_3 bending vibrations.

The functional groups indicate the formation of a carboxylic acid. As previously noted, the gum base is often composed of polyvinyl acetate, as shown in Figure 5 [43]:

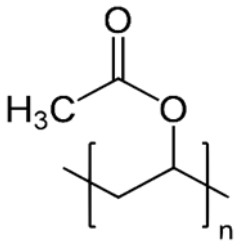

Figure 5 Polyvinyl acetate structure [43].

It can therefore be inferred that the pyrolysis of discarded chewing gum breaks the bond between the secondary carbon and the oxygen present in the structure shown above, thereby forming ethanoic acid, commonly known as acetic acid. Confirmation of this process was analyzed by gas chromatography-mass spectrometry, as presented in the next section [44, 45].

3.5.2 CG-MS

Using gas chromatography coupled with mass spectrometry on the samples that produced bio-oil at an initial pressure of 15 bar, with a minimum similarity index (SI) of 85 and excluding the solvent used (in this case, isopropanol), ethanoic acid (SI 97) was identified, confirming the initial suspicion, as well as acetaldehyde (SI 87), as shown in Table 8 [46].

Table 8 GC-MS composition of the bio-oil obtained from pyrolysis of discarded chewing gum at an initial pressure of 15 bar.

Temperature (°C)	Time (min)	Acetaldehyde (%)	Acetic acid (%)
300	40	ND	94.56
350	40	ND	84.45
350	60	5.52	64.76
350	120	ND	83.37

As supported by spectral analysis, ethanoic acid was the predominant compound identified. Furthermore, acetaldehyde was identified exclusively in the bio-oil produced at a temperature of 350°C and a reaction time of 60 min; this product is likely formed by the breaking of the bond between the primary carbon and oxygen, which is prone to occur at lower pressures due to its low boiling point [47-49].

3.5.3 Decarboxylation and Decarbonylation Mechanisms in the Pyrolysis of Chewing Gum

The bio-oil obtained in the study consists predominantly of ethanoic acid with occasional formation of acetaldehyde, indicating thermal degradation of the gum and a degradation pathway primarily composed of chemical reactions typical of oxygenated vinyl polymers [41, 42, 48].

These pathways are governed primarily by elimination processes (deacetylation), followed by secondary reactions, notably decarboxylation and decarbonylation, particularly at higher temperatures and longer reaction times. In the reaction sequence, the formation of products is governed by: (i) deacetylation of PVAc with the formation of acetic acid; (ii) secondary decomposition of this acid via decarboxylation (generating CO_2) and decarbonylation [21, 24, 37].

Initially, the dominant step is the thermal deacetylation of PVAc, in which the acetate group linked to the polymer chain is eliminated, generating acetic acid and an unsaturated polymer chain (a polyene), as shown in Figure 6. This process typically occurs in the range of 300-400°C, is favored in an inert atmosphere, and represents the main degradation pathway of the polymer. The reaction can be described as an intramolecular elimination, initiated by thermal excitation and propagated along the chain [21, 41, 42].

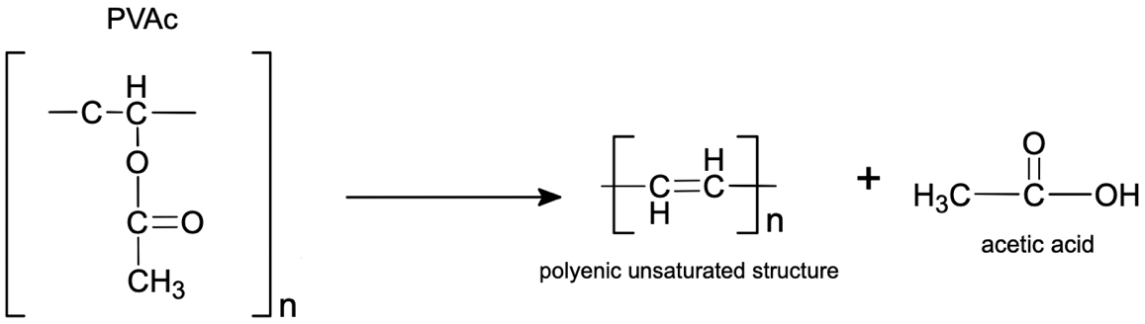

Figure 6 Deacetylation mechanism of PVAc [21].

From this point on, the acetic acid formed undergoes secondary thermal decomposition, with decarboxylation and decarbonylation as the main pathways [21]. The decarboxylation of acetic acid occurs through thermal cleavage and removal of the carboxyl group, resulting primarily in the

formation of CO_2 and water (H_2O), This process can be described as a heat-induced homolytic cleavage, with the formation of methyl and hydrogen radicals, as shown in Figure 7.

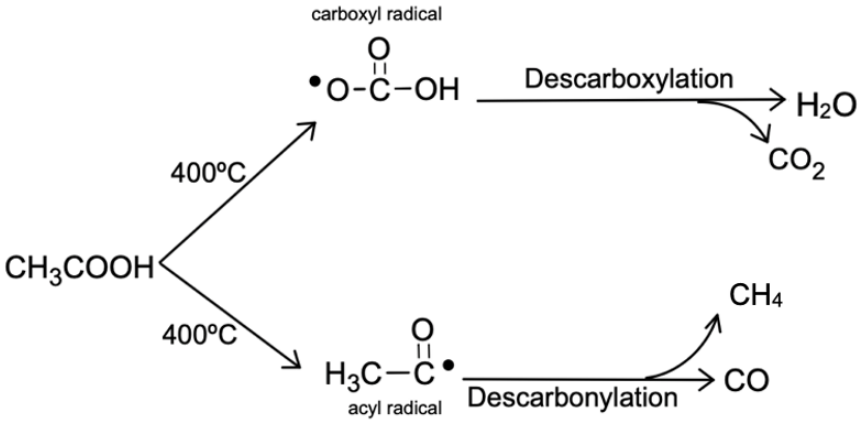

Figure 7 Mechanism of decarboxylation and decarbonylation [21].

From a mechanistic standpoint, both decarboxylation and decarbonylation reactions are initiated by radical processes characteristic of pyrolysis. Thermal energy promotes the homolytic cleavage of bonds in the polymer chain and in the intermediates, generating highly reactive free radicals that undergo β-scission, rearrangements, and elimination reactions [21, 42].

In contrast, decarbonylation involves the removal of the carbonyl group (CO), associated mainly with the decomposition of intermediate fragments of the polymer chain, rather than isolated acetic acid. In the system studied, the formation of acetaldehyde can be explained by a pathway involving polymer chain fragmentation and the formation of unstable vinyl and enol radical intermediates [23, 43]. This mechanism is favored at higher temperatures and under prolonged reaction times, which is consistent with the experimental results, in which an increase in the gaseous fraction is observed at the expense of bio-oil under more severe conditions. Thus, the formation of CO_2 directly contributes to the observed increase in the non-condensable gaseous phase [44, 45]. The experimentally observed presence of acetaldehyde, especially under lower-pressure conditions, reinforces the occurrence of this pathway, since more volatile compounds are favored in systems with shorter reaction times, facilitating their removal from the condensable phase [41, 42, 46].

Furthermore, the predominance of acetic acid in the bio-oil suggests that, under the identified optimal conditions (350°C and 60 min), the rate of formation via deacetylation exceeds the rate of consumption via decarboxylation/decarbonylation. However, at longer times (120 min), a decrease in the liquid fraction and an increase in the gas phase are observed, indicating that these secondary reactions begin to dominate the system, converting the previously formed bio-oil into non-condensable gases [47]. For reactions conducted at an initial pressure of 70 bar, the samples exhibited the results shown in Table 9 [48, 49].

Table 9 GC-MS composition of the bio-oil obtained from pyrolysis of discarded chewing gum at an initial pressure of 70 bar.

Temperature (°C)	Time (min)	Acetic acid (%)
300	20	76.39
300	40	88.10
300	60	88.21
325	60	87.36
350	20	77.74
350	40	76.60
350	60	88.51
350	120	85.44

In general, pressure did not significantly affect the products obtained, except for acetaldehyde formation at 15 bar. Conversely, under high-pressure conditions, only the elimination reaction occurs, leading to the formation of ethanoic acid, since it has lower volatility and pressure in the system than acetaldehyde [42, 50, 51].

The highest concentration of acetic acid (94.56%) was obtained from the reaction conducted at 300°C and for 40 min at 15 bar. Under these pressure conditions, increasing the time and temperature reduced the concentration of ethanoic acid [52]. In contrast, for the experiments at 70 bar, the chosen temperature gradient appears to have little relevance to the concentration obtained, since at 300°C, 325°C and 350°C, with the same reaction time, there was negligible variation.

4. Optimal Pyrolysis Conditions

The largest bio-oil production occurred at 350°C and 60 min, yielding 2.20 g and 1.64 g at initial pressures of 15 and 70 bar, respectively. Under these conditions, the acetic acid concentrations were 64.76% and 88.51%. The highest acetic acid concentration measured was 94.56% at 300°C, 40 min, and 15 bar. Thus, the condition that produced the largest amount of bio-oil differed from the condition that produced the highest acetic acid concentration. At 120 min, bio-oil production decreased, and the gaseous fraction increased for both pressure levels.

5. Overall Discussion of Product Formation

The pyrolysis of discarded chewing gum showed behavior similar to that reported for polyvinyl acetate (PVAc), the main component of the gum base. FTIR and GC-MS analyses indicated the predominance of oxygenated compounds, particularly acetic acid, which is a characteristic product of PVAc degradation [21, 41].

The composition of the bio-oil differed from that commonly reported for polyethylene, polypropylene and polystyrene. The pyrolysis of these polymers generally produces mixtures containing hydrocarbons distributed over different boiling ranges. In the present study, acetic acid was identified as the main product in all samples analyzed by GC-MS. This result is consistent with the presence of PVAc in the gum base and with its known degradation pathway [24].

The predominance of acetic acid is related to deacetylation reactions, which occur during the thermal degradation of PVAc. In this process, acetate groups are removed from the polymer chain,

producing acetic acid and unsaturated structures in the remaining material. Acetaldehyde was detected only under low-pressure conditions, suggesting that product formation was dependent on the reaction conditions [41, 42].

The product distribution obtained in this work differs from that reported for plastic mixtures rich in polyethylene, polypropylene and polystyrene, where liquid hydrocarbons and carbonaceous solid residues are commonly formed. The results from discarded chewing gum indicate a conversion route directed mainly toward oxygenated compounds, with acetic acid as the predominant product [50].

6. Conclusion

Discarded chewing gum was subjected to pyrolysis at temperatures between 300 and 350°C, reaction times between 10 and 120 min, and initial pressures of 15 and 70 bar. The largest bio-oil production was obtained at 350°C and 60 min, yielding 2.20 g and 1.64 g at initial pressures of 15 and 70 bar, respectively. The highest acetic acid concentration was 94.56%, obtained at 300°C for 40 min and 15 bar.

FTIR and GC-MS analyses identified acetic acid as the predominant compound in the liquid fraction. Acetaldehyde was detected only in experiments conducted at 15 bar. The composition of the products was associated with the thermal degradation of polyvinyl acetate present in the gum base.

The results show that discarded chewing gum can be converted into liquid products with high acetic acid concentrations under relatively mild pyrolysis conditions. The composition of the bio-oil differed from that commonly reported for polyethylene, polypropylene and polystyrene, indicating that the presence of polyvinyl acetate strongly influences the distribution of products formed during thermal degradation.

The experimental data obtained in this work establish operating conditions for the conversion of discarded chewing gum and provide information on the influence of temperature, reaction time and pressure on product distribution. Considering the limited number of studies available for this residue, the results contribute to understanding its thermal conversion and provide a basis for future investigations involving product recovery and process development.

Author Contributions

Author Thiago Soares Penha was responsible for the development and experimental execution of the project; Dr. Romulo Davi Albuquerque Andrade led the data collection and technical-scientific discussion for the entire project, and wrote, discussed, and revised the entire article; Dr. Paulo Anselmo Ziani Suarez was responsible for conceiving the project, coordinating activities, conducting and monitoring the experiments, discussing the results, and writing and revising the entire article.

Competing Interests

The authors declare no conflicts of interest.

AI-Assisted Technologies Statement

Artificial intelligence (AI) tools were used exclusively for basic grammatical correction and language refinement in the preparation of this manuscript. Specifically, Linguee was used to improve the readability and linguistic clarity of the English text. All scientific content, data interpretation, and conclusions were developed independently by the authors.

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