Conversion of Municipal Solid Wastes into Fuels and Chemicals by Pyrolysis: Tulkarm Transfer Station as a Case Study.

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Abstract: **This study examines the process of pyrolysis, which turns municipal solid waste (MSW) into chemicals and fuels. The Tulkarm Transfer Station in Palestine is used as a case study. Aspen Plus process simulation is used in the study to assess technical performance, environmental advantages, and economic viability in a variety of situations. A rotary kiln reactor model was created to forecast product yields, and proximate and ultimate analyses were used to characterize the composition of MSW. The results demonstrate that the heterogeneous character of the feedstock has a major impact on the pyrolysis results.**

The pyrolysis process of the MSW was simulated in various scenarios, with the first scenario achieving a maximum bio-oil production of 21.3 wt.%. The second scenario, which focused on the biomass portion, yielded 60.5 wt.% bio-oil. However, the third scenario (50% plastic with 50% biomass) and the fourth scenario (100% plastic feedstock) had maximum bio-oil yields of 67.82% and 82.32 wt%, respectively.

When compared to landfilling, economic analysis shows that scenarios that include energy recovery and the sale of chemical byproducts offer the maximum profitability while simultaneously lowering greenhouse gas emissions. The results show that pyrolysis has the potential to help Palestine with its energy and waste management issues. This study advances the local use of waste-to-energy technology by offering a framework that may be replicated in comparable situations in underdeveloped nations.

***Keywords*—Municipal solid waste, pyrolysis, Aspen Plus, waste-to-energy, economic feasibility, Palestine.**

I. INTRODUCTION

According to a United Nations study, there will be 9.7 billion people on the planet in 2050, up from 7.7 billion in 2019 [1]. In mid-2021, there were 5,227,193 people living in the Palestinian Territories (PT), with 3,120,448 in the West Bank and 1,210,674 in Gaza [2]. Increases in per capita waste production, energy consumption, and reliance on fossil fuels have all increased as a result of this population growth [3]. In Palestinian areas, municipalities and joint service councils are finding it difficult to handle the growing solid waste issue. According to the Ministry of Local Government's 2019 Data Book, MSW output averaged 2600 tons per day, or 0.91 kilos per person. Eighty-three percent of the generated MSW is collected by the JSC; the remaining amounts are collected by Local Governmental Units (LGU), and the United Nations Relief and Works Agency (UNRWA) [4]. Landfills are commonly used in developing countries for waste management, but they can reduce waste volume and weight by 90% and 70%, respectively, and they also raise concerns about environmental degradation of soil, water, and air [5]. Pyrolysis is a crucial WtE technique that addresses both fossil fuel depletion and MSW accumulation, producing heat, electricity, and various fuels and chemicals.

The accumulation of MSW in Palestinian territory has a harmful impact on the environment and citizens' health. The three West Bank landfills, Zahrat Al-Finjan in Jenin, Jericho landfill, and Al-menia in Beitlahm, are overloaded with 88%, >100%, and 9% utilization rates, respectively [6]. While the existing transfer stations are inadequate to handle the growing volumes of MSW, and pre-treatment procedures are not implemented before transporting to accessible landfills in the PT. To take benefit of the crisis, MSW treatment processes can be transformed into long-term energy production through waste-to-energy (WtE) solutions, including thermal conversion techniques, biochemical conversion methods, and landfilling [7]. Pyrolysis produces oil with closely monitored quality and easier transport and is safer for the environment than other thermal treatment systems [8].

The Palestinian Authority should not focus on producing electricity for sustainable MSW disposal due to economic and political reasons. The lack of infrastructure and costly pre-treatment activities make it unfeasible. Instead, the focus should be on using WtE technology to produce fuels, as there is no reliable crude oil in the Palestinian Territories for electricity generation, factories, farm machinery, and transportation. The Palestinian Authority also lacks its own fuel reserves, and the only fuel available is from Israel, which is only available for 48 hours if supplies are cut off [9], [10].

The pyrolysis process can be carried out in a variety of typical reactor designs, including fixed-bed, fluidized-bed, rotary kiln, auger or screw, and ablative reactors. Fixed-bed reactors, the oldest type of reactor, have disadvantages such as sluggish heating rates and long residence times, but they perform well with MSW feedstock of uniform size. Because they generate bio-oil and are more productive due to their continuous feedings, fluidized-bed reactors are widely used in the chemical and oil sectors. Because of its moderate residence time and heating rate, a rotary kiln reactor is a useful method for MSW pyrolysis. Auger reactors move biomass substrate through a heated tube to convert feedstock into bio-oil and recover biogas. Due to their melted layer and lack of fluidizing gas, ablative reactors are not suitable for scale economies [8] [11] [12].

Temperature is one of the most important variables influencing the pyrolysis process; it can influence the amount of bio-oil produced by 10% to 20%. Generally, temperatures between 450 and 550°C are appropriate for the synthesis of liquid biofuel. Heating rate is another important aspect of pyrolysis reactors that affects the breakdown patterns that differentiate slow pyrolysis from quick pyrolysis. It has a direct impact on the characteristics and makeup of the gas, charcoal, and bio-oil components. The residence time is the amount of time the raw material is exposed to a specific temperature. For batch processing activities to produce the desired pyrolysis product, this time must be adequate. Additionally, pretreatment methods, catalysts, reaction environment, and feedstock particle size all have a big impact on the pyrolysis process. [13] [14].

The pyrolysis process produces biochar, bio-oil, and syngas. Syngas is made up of light components, including H_2, CO, and CO_2, whereas pyrolysis oil contains hydrocarbons, aromatic hydrocarbons, benzene derivatives, and oxygenates [36]. Biochar is made from solid remains from MSW pyrolysis, mostly carbon, metals, inorganic compounds, and transition elements. High temperatures promote the generation of syngas from biomass but inhibit the creation of biochar [31]. However, as temperature is one of the most important factors in the pyrolysis process, the right pyrolysis temperatures must be adjusted for oil production [15] [16] [17] [18].

II. Research Methodology

This This research uses a rigorous modeling approach and reliable process simulation to investigate thermal pyrolysis in the West Bank (WtE), particularly for the production of valuable chemicals and biofuel. The study demonstrates the potential of MSW in producing bio-oil and chemicals by providing detailed information on slow pyrolysis and serves as a framework for future studies in this field. The findings are highly reliable, despite being based on computer software and not having practical application in the West Bank. The research will rely on both qualitative and quantitative data collection and analysis. The qualitative approach involves an interview with a key person at the JSC in Tulkarm, as the case study, and extensive research to determine optimal pyrolysis features. The quantitative approach involves analyzing numerical MSW quantity data and creating equations and parameters for the process simulation. The methodology is depicted in Fig. 1

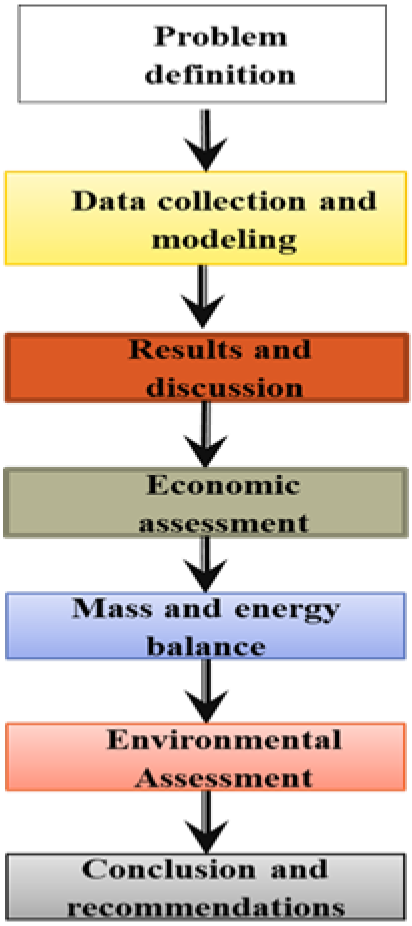


Fig. 1: Methodology flowchart

The quantitative approach involves analyzing numerical MSW quantity data and creating equations and parameters for the process simulation. The methodology is depicted in Fig. 2.

III. Data Collection

For the aim of obtaining data, JSC in Tulkarm was utilized to obtain broad details like the size of Tulkarm TS, the number of LGUs it serves, and the procedure of gathering MSW. The amount and nature of garbage the TS receives, however, are of vital importance. To acquire a thorough picture of the situation in the PT with regard to MSW management, several kinds of literature in addition to national reports from the Palestinian Central Bureau of Statistics (PCBS) were also viewed. A comprehensive investigation of thermal pyrolysis to produce bio-oil and chemicals, as well as its simulation, was conducted.

IV. Analysis Criteria

This study's analysis was conducted using a quantitative methodology. To establish the proper equations and parameters for modeling, as will be demonstrated in this part, the quantitative approach will first be utilized to assess the composition of MSW for ultimate and proximate analyses as well as its heating value for each scenario. Four different scenarios will be adopted in this study to investigate the pyrolysis temperature at which the maximum yield of bio-oil occurs and to comprehend how the feedstock composition affects the pattern of biofuel production. In Scenario NO.1 (Unmodified MSW), pyrolyzing the intended MSW with all of its components (biomass, paper, plastic, rubber, and textiles) without any alterations is proposed. In Scenario NO.2 (Just biomass), the majority of the specified MSW, which is biomass, is advised to be pyrolyzed. while the MSW biomass fraction and plastic trash are co-pyrolyzed in a 50/50 ratio in Scenario NO.3 (50% Biomass with 50% Plastic). The last scenario is Scenario No. 4. The pyrolyzing raw material is exclusively made up of plastic waste; the polymers used are LDPE, HDPE, PP, and PET. The main contents and percentages after screening materials such as glass, metals, and rocks for the four scenarios are presented in Table 1.

A. Analysis of MSW components

A cumulative average is computed based on the ultimate and proximate analysis of the MSW's individual components [19], as well as the percentages of those components, to determine the total ultimate and proximate analysis for the proposed feedstock in the four scenarios. Paper is separated into two equal parts: paper and cardboard; textiles are classified into three equal parts: cotton fabric, absorbent cotton gauze (ACG), and terylene (TE); and plastic is divided into four equal parts: HDPE, LDPE, PET, and PP. Table 1 depicts the ultimate and proximate analysis of the feedstock components in addition to its heating value.

B. The pretreatment processes.

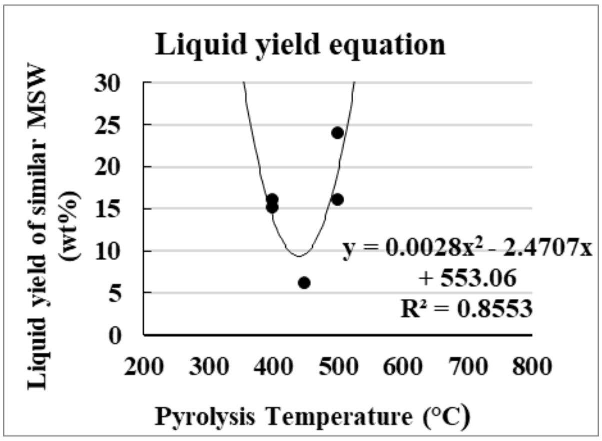
As part of the pretreatment process for pyrolysis, MSW is screened to remove solid components, the screened feedstock is dried for 24 hours at 105°C, and it is then shredded to the proper particle size—10 mm is employed [11] [20].

C. Co-pyrolysis reactor and characteristics

A rotary kiln reactor has been proposed since it is often used for the industrial-scale pyrolysis of MSW and offers sufficient heat transfer with comparatively little energy usage [11]. We recommend using a heating rate and residence duration of 15°C/min and 30 min., respectively, based on experiments conducted by many researchers [20]. [21] [22] Pyrolysis simulation has been performed over a wide range of temperatures, from 300 to 800°C.

D. Preparing for simulation

In order to obtain results from Aspen Plus, we, therefore, created the necessary variables and equations for each and every output material in the simulation we did using the experimental data that was provided. It's also important to keep in mind that Aspen Plus is a precise program, meaning that even the smallest error in the user's input results in an error and occasionally prevents the program from moving on to the next phase.



Error! Reference source not found.: Trendline of liquid yield from MSW

The type of reactor selected will determine how to set up the simulation's key equations and parameters; in our case, the stoichiometry reactor (RStoic) was used. For each of the proposed reactions in the pyrolysis process, this sort of reactor necessitates the insertion of a reaction coefficient and a fractional conversion in addition to pyrolysis pressure and temperature. Simply put, the reaction coefficient is constant regardless of the temperature of pyrolysis and equals the multiplicative inverse of the substance that results. Conversely, figuring out the conversion factor is a more complicated procedure. the conversion factor for each product was calculated, which will change depending on the temperature of pyrolysis, using formulae based on the realistic outcomes of various pyrolysis studies for circumstances similar to our own [11], [23]. In **Error! Reference source not found.**, the calculated reaction coefficients and fractional conversion equations are illustrated.

To construct fractional conversion equations for any product type, the gathered findings from works of literature were plotted, then the desired equation was established from its polynomial trending line, as illustrated in **Error! Reference source not found.**. Based on their ultimate and proximate analysis, the employed feedstock and char components were classified as non-conventional components (as shown in each scenario). The base property method for the entire system is the Peng-Robinson cubic equation of state with the Boston-Mathias alpha function (PR-BM).

E. Simulation of pyrolysis

Error! Reference source not found. depicts the production piping and instrumentation diagram for bio-oil. In the RStoic reactor, the MSW was decomposed. In the RStoic reactor, the solid waste was divided. The vapor-liquid combination was cooled and separated into gas and liquid yields in a separator. The gas created during pyrolysis was crucial because it provided the necessary heat for both pyrolysis and drying the feedstock.

V. RESULTS AND DISCUSSION

This study focuses on feedstock and pyrolysis conditions while analyzing four different scenarios for producing biofuel and chemicals from MSW. For slow pyrolysis, the rotary kiln reactor was suggested at 300–800°C and 1 bar of pressure. The RStoic Aspen Plus reactor was selected for the analysis of the components of raw materials. Each scenario's coefficients and fractional conversions were detailed separately.

A. Scenario NO.1: Unmodified MSW

The yields of the gas, liquid, and solid pyrolysis products are shown in **Error! Reference source not found.** In fact, our simulation results are in line with several other studies when compared to a number of real-world experiments conducted in the same field. For example, pyrolyzing MSW up to 700 °C produced a liquid yield of 13–32 weight percent for Wang et al., which was comparable to the 18–32 weight percent for Song et al. Gandidi et al. achieved a maximum liquid yield of 15.2 weight percent at 400 °C [20], [21][22] Biomass, which makes up the majority of the suggested feedstock, degrades at low temperatures. Pyrolysis yields below this temperature are not simulated because the Aspen Plus program's calculations are accurate for temperatures between 300 and 800°C.

B. Scenario NO.2: Just biomass

Error! Reference source not found. displays the gas, liquid, and solid pyrolysis product yields. A little after 300°C, liquid yield starts to form; at 550°C, the maximum liquid yield was 60.5%. On the other hand, the highest oil yield from biomass in some practical experiments for other researchers was 64.57% by weight and 57.56% by weight at 600°C [24], [25].

C. Scenario NO.3: 50% Biomass with 50% Plastic

The results of the third scenario were similar to those of the second, although the production of gas and charcoal was generally lower, and the productivity of bio-oil was higher. As in the previous scenario, the maximum oil yield is attained at 550°C, but it is 7 weight percent higher; it reached 67.82 weight percent (**Error! Reference source not found.**). These findings are extremely similar to some real findings from earlier research [24], [25].

D. Scenario NO.4: Just plastic

The outcomes of pyrolysis employing only plastic as a raw material are presented in this part, as seen in **Error! Reference source not found.**. In fact, the bio-oil yield peaked at 375°C with 82.32 weight percent, then dropped to its lowest productivity at 800°C with 40 weight percent. The process of thermally pyrolyzing plastic trash to produce bio-oil has been extensively studied in the literature. There are several similarities between our research results and the findings in the literature. According to Anuar Sharuddin et al.'s overview of numerous studies, the highest yields from the pyrolysis of HDPE, LDPE, and PP are 80.88 weight percent, 80.41 weight percent, and 80.1 weight percent, respectively, at temperatures of 350, 500, and 380°C [26].

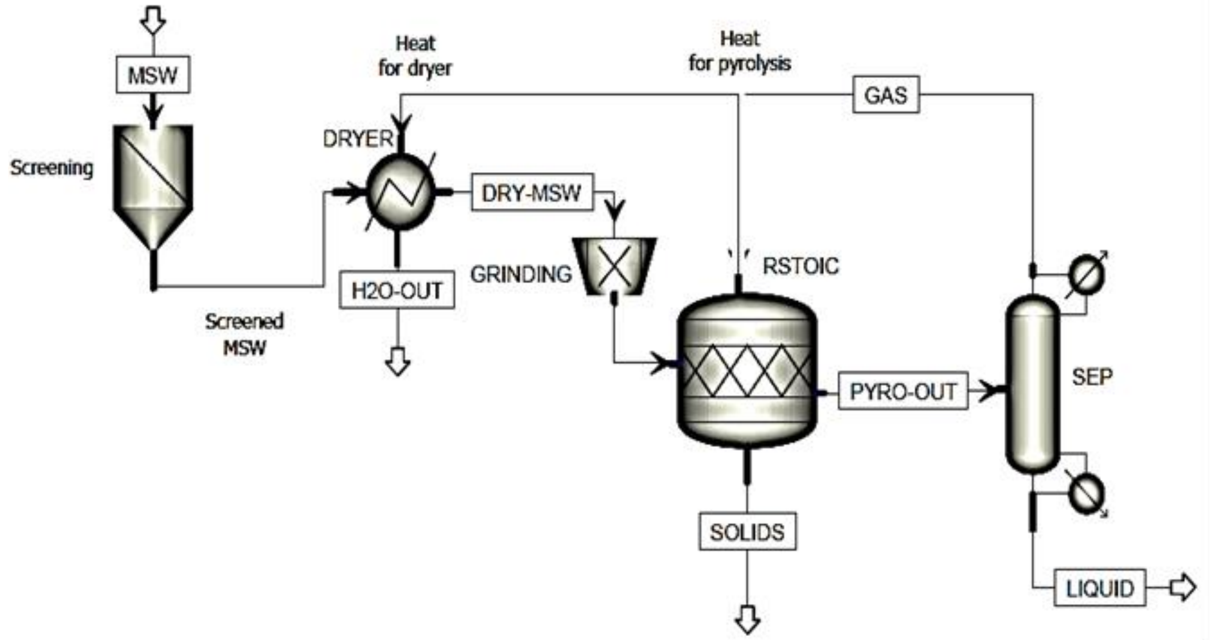


Fig. 3: P & ID of decomposition and pyrolysis of MSW components

Table 1: feedstock specifications for the proposed scenarios

MSW component	***Adjusted mass ratio (wt.%)***	***Mass ton/day***	***Proximate analysis (wt.% dry basis)***		***Ultimate analysis (wt.% dry basis)***	
Scenario NO.1						
Dry Biomass	49.31	78.4	***Ash***	20.20	***C***	41.15
Paper and cardboard	15.09	24	***VM***	50.08	***H***	5.00
Plastics	6.29	10	***FC***	7.85	***N***	1.43
Textiles	7.55	12	***Moistur***	21.87	***S***	0.67
Rubber	0.63	1			***O***	31.55
Moisture	21.13	33.6				
Total mass = 200 tons/day			HHV (MJ/kg) = 14.59236			
Scenario NO.2						
Dry Biomass	70	78.4	***Ash***	25.3	***C***	37.723
Moisture	30	33.6	***VM***	37.4	***H***	4.6
Total mass = 112 ton/day			***FC***	7.4	***N***	1.85
			Moistur	29.9	***S***	0.88
					Cl	1.047
					O	28.6
			HHV (MJ/kg) = 11.956			
Scenario NO.3						
Dry Biomass	35	78.4	***Ash***	12.66	***C***	54.083
Moisture	15	33.6	***VM***	66.24	***H***	7.13
Plastic	50	112	***FC***	4.89	***N***	0.98
Total mass = 224 tons/day			***Moistur***	16.21	***S***	4.5
					Cl	1.047
					O	19.6
			HHV (MJ/kg) = 26.12			
Scenario NO.4						
HDPE	35		***Ash***	0.06	***C***	73.62
LDPE	29		***VM***	95.841	***H***	8.26
PP	21		***FC***	2.534	***N***	1.08
PET	15		***Moistur***	1.565	***S***	0.023
					Cl	0
					O	16.957
			HHV (MJ/kg) = 36.8			

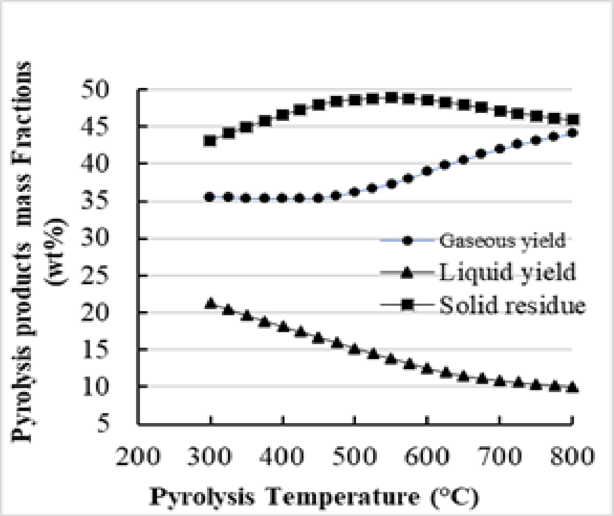
E. Liquid yield in all scenarios

Given that the goal of our research is to examine the possibility for creating bio-oil and chemicals from MSW, it is essential to review the liquid yields that were calculated using Aspen Plus simulation for the four scenarios that were put out. In contrast to the unmodified MSW, the pyrolysis of plastic wastes, as shown in **Error! Reference source not found.**, produced the most liquid product out of all the suggested scenarios. This highest yield occurred at a lower temperature range compared to the second and the third scenarios. This can be explained by the fact that plastic types (PS, PET, PP, LDPE, and HDPE) break down in a limited temperature range of 311–480°C [27]

Error! Reference source not found.: *Simulation specifications for the proposed scenarios*

Common specifications between the four scenarios	
Property Method	PR-BM
Reactor type	RStoic
Pyrolysis Temperature	300-800 °C
Pyrolysis pressure	1 bar
Reactions coefficients	
Gaseous Yield	0.66
Liquid Yield	0.08
Biochar Yield	1
Fractional conversion relevant equations of Scenario NO.1	
GY	FC (gas) = 0.000002 x^2 - 0.0023 x + 1.0556
LY	FC (oil) = 0.0000007 x^2 - 0.0011 x + 0.6196
CY	FC (biochar) = the summation minus one.
Fractional conversion relevant equations of Scenario NO.2	
GY	FC (gas) = 0.0008 x^2 - 0.6643 x + 154.57
LY	FC (oil) = -0.0013 x2 + 1.4061 x - 316.52
CY	FC (biochar) = the summation minus one.
Fractional conversion relevant equations of Scenario NO.3	
GY	FC (gas) = 0.0002 x^2 - 0.1476 x + 49.571
LY	FC (oil) = -0.0007 x2 + 0.7682 x - 141.53
CY	FC (biochar) = the summation minus one.
Fractional conversion relevant equations of Scenario NO.4	
GY	FC (gas) = 0.0002 x^2 - 0.1176 x + 34.929
LY	FC (oil) = -0.0005 x^2 + 0.4889 x - 24.775
CY	FC (biochar) = the summation minus one.
x represents the pyrolysis temperature in degrees Celsius.	

The high yields of liquid products produced by pyrolysis of biomass and biomass/plastic are produced in a converging range of temperatures and amounts. However, it should be mentioned that the liquid yield from the pyrolysis of the biomass/plastic mixture is of higher quality than the other one, which had a lower amount of water. For instance, when cedar was pyrolyzed without the use of plastic, the yield of liquids was 64.57 wt.% at 600°C, of which 25.74 wt.% was water. The liquid yield, on the other hand, was 80.02 wt.% with 15.94 wt.% after pyrolyzing a mixture of equal parts biomass and plastic at the same temperature [45]. The "maximum oil yield" temperature changed from 300°C in the first scenario to 550°C in the second and third scenarios as a result of the varied feedstock compositions between the first scenario and both the second and third scenarios. In the first scenario, the feedstock was made up of a number of different components, which had a synergistic effect on the optimal temperature in contrast to what happened in the second and third cases.



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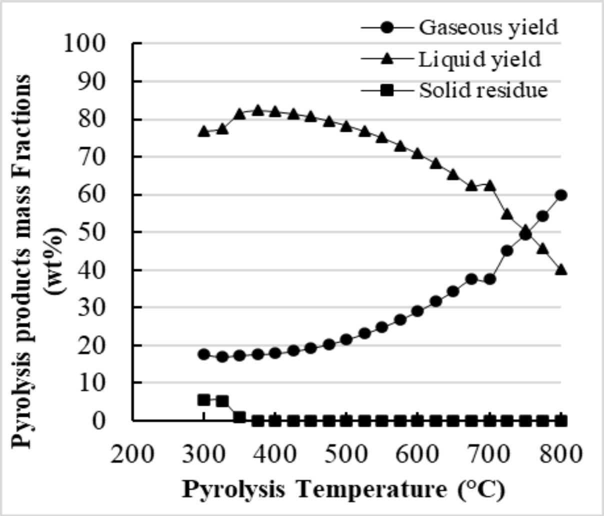

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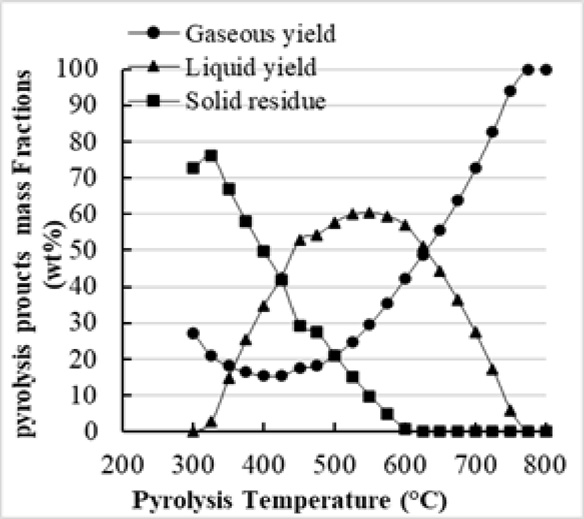

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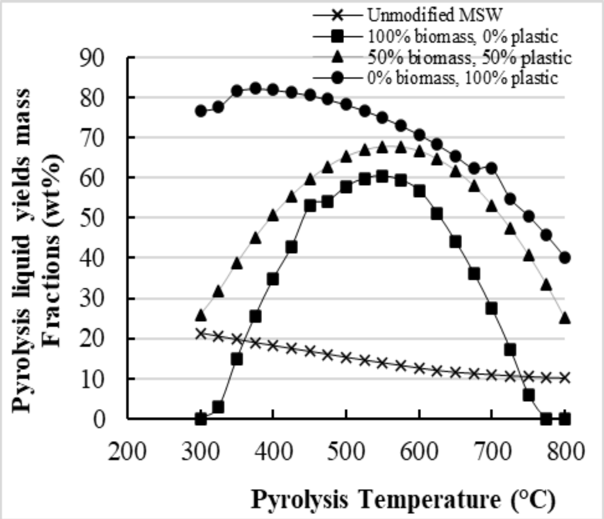

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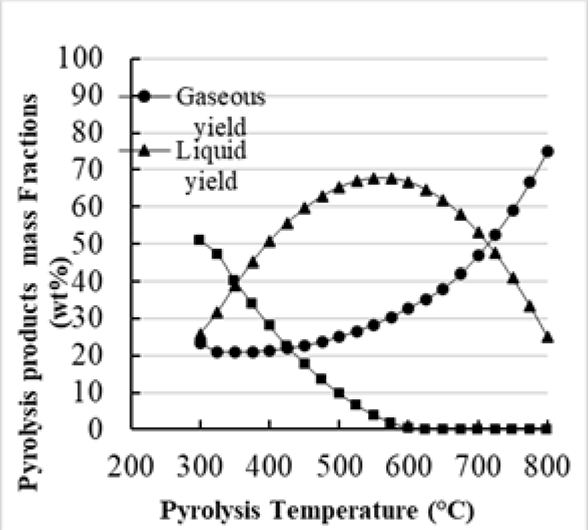

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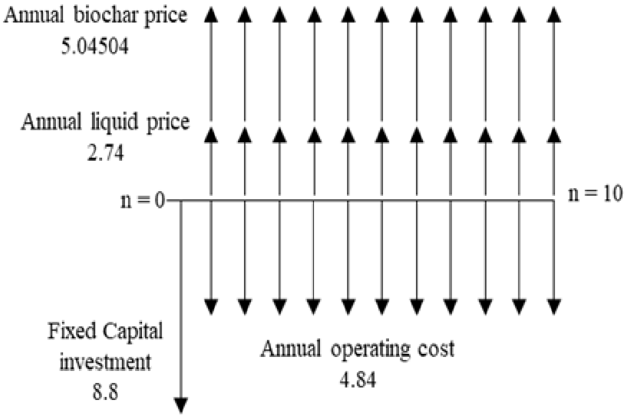
VI. ECONOMIC FEASIBILITY ASSESSMENT

Although the first scenario may be the least feasible from an economic perspective, we have conducted the economic evaluation for it in this study because it is the most realistic in terms of raw material availability. Evidently, the suggested feedstock naturally yields more biochar and less bio-oil, both of which are of the lowest quality when compared to the others. In other words, the other scenarios will be feasible if the first one is.

To determine the pyrolysis process's commercial feasibility, an economic study that takes into account both production costs and profit is essential. The process costs are separated into capital costs, such as plant price, and operational costs. The estimated percentages of contributions from each component to variable costs are listed in Table 3 [28]. The assumptions and expenses of the main factors utilized in this economic study to assess the viability of the selected pyrolysis plant, with a capacity of 200 tons/day, are shown in Table 2 [12]. The cash flow diagram for the first scenario is shown in **Error! Reference source not found.** with the aid of the data previously stated. **Error! Reference source not found.** provides a summary of our economic analysis' results.

According to the previous study, the proposed project is obviously profitable and has the ability to manage unforeseen expenses because of its high internal rate of return. Also, it should be mentioned that the price of the used biochar in this instance is less than market prices because the quality of the biochar generated can differ based on the type of feedstock used.



Error! Reference source not found.: Cash flow diagram of pyrolysis plant implementation; costs are in millions of dollars.

Table 3: A rough estimate of each component's contribution to the variable cost.

Items	Percenta
Biomass feedstock	23-30
Maintenance	17-24
Utilities	22-25
Labor	12-19
Grinding	7-9
Transportation	5-7

Error! Reference source not found.: Results of the proposed project's economic analyses

Financial metric	The value
Net Present Value (NPV)	$9.33 million
Annual Worth (AW)	$1.52 million
Simple Payback Period (SPBP)	3 years
Product Cost per ton of bio-oil	182 $
Discount Payback Period (DPBP)	3.71 years
Internal Rate of Return (IRR)	31.32%
LCOE	0.176 US$/kWh

VII. MASS AND ENERGY BALANCE

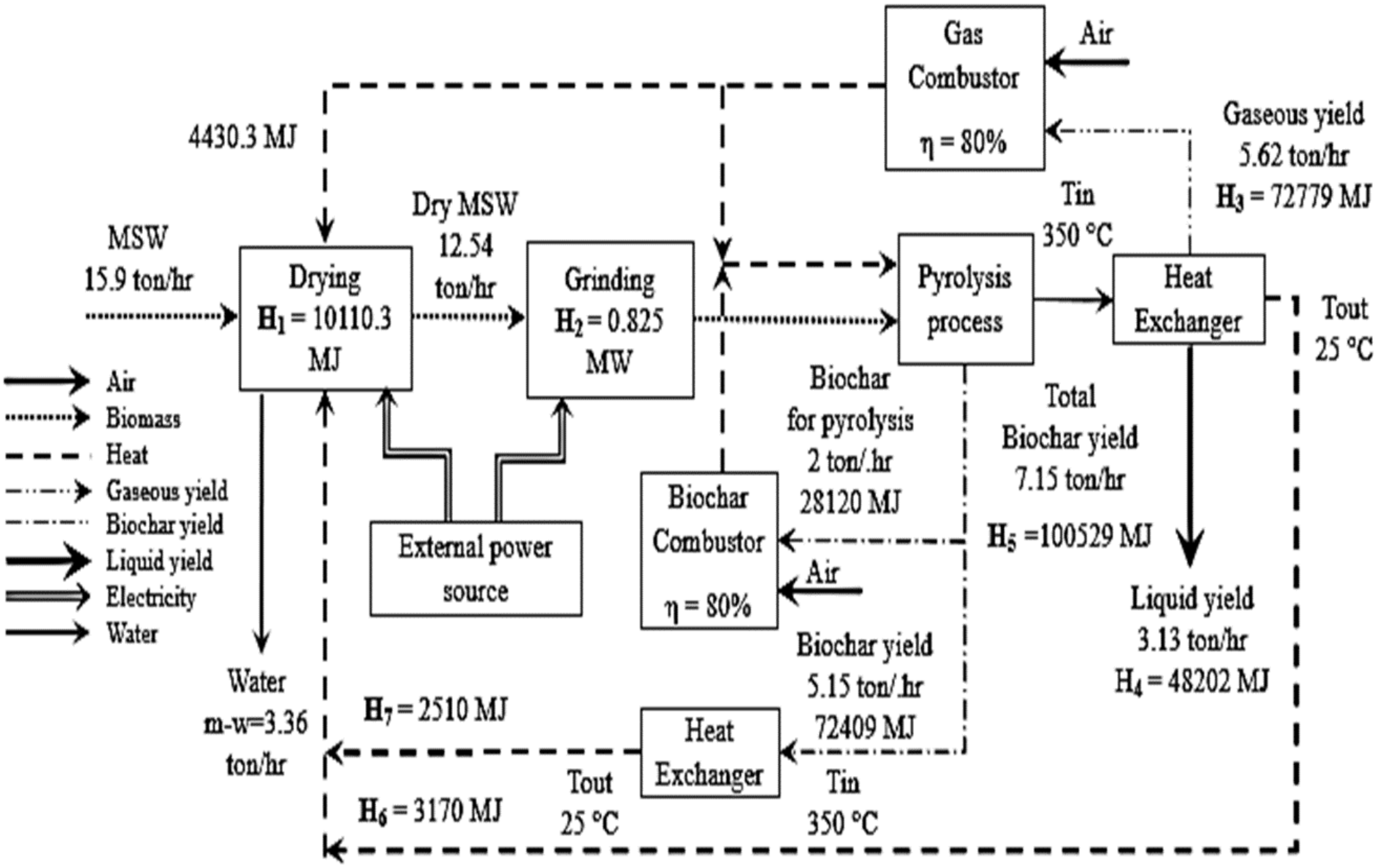
The energy and mass flow of the pyrolysis process, with 10 operational hours and 159 tons of MSW per day, are illustrated in **Error! Reference source not found.**. Every figure in this block diagram was computed using the specifics of the first scenario that we previously suggested. Several scientific studies provided the required data and formulas [29] [7] [30] [20].

VIII. ENVIRONMENTAL ASSESSMENT

As a clean fuel produced by pyrolysis, bio-oil provides significant environmental advantages over fossil fuels. Biofuels have a CO_2/GHG neutrality; they can therefore earn carbon dioxide credits. In terms of transportation, transportation bio-oil made from MSW's organic material sequesters 9.5 g of CO_2 equivalent per MJ of biofuel, compared to the 95.5 g of CO_2 equivalent released by existing fossil transportation fuels [31]. Based on a study by Rajaeifar et al., the production of 1 MWh of electricity from fossil fuels results in an average environmental impact of 658.1 kg CO_2 eq (182.8 g CO_2 eq per MJ). The average amount of GHG emissions to the environment could be reduced by 700.4 kg CO_2eq (194.56 g CO_2eq per MJ) and 854.7 kg CO_2eq (237.42 g CO_2eq per MJ), respectively, when generating 1 MWh of electricity from MSW utilizing a combination of AD and incineration technologies or by utilizing the combination of AD and pyrolysis-gasification technologies [32]. Since the sulfur content of plant biomass is negligible, no SOx emissions are produced. In a gas turbine, bio-oil fuels produce NOx emissions that are more than 50% lower than those from diesel fuel. Bio-oils are therefore less polluting and cleaner [33]. However, the solid, liquid, or gas products of pyrolysis may still include certain pollutants. S, N, and Cl are volatile elements. But the effects of pyrolysis on the environment can be reduced in a number of ways. The use of catalysts to improve product quality, the interception of HCl, SO_2, and NH_3 in the gaseous phase, and the omission of some particular feedstock constituents are among these procedures [11].

IX. CONCLUSION

This study examines MSW pyrolysis's potential as a dependable renewable energy source for the synthesis of chemicals and bio-oil. In the four scenarios that were created, the plastic ratio was the most important variable. In the first scenario, the highest bio-oil yield of 19.7 weight percent was not high because biomass constituted the majority of the feedstock. At 550°C, the maximum amount of bio-oil produced in the second scenario was 60.49 weight percent, whereas the maximum amount produced in the third scenario was 67.82 weight percent. The best oil output of 82.32 weight percent was obtained in the fourth scenario, which employed just plastic as a feedstock. In order to solve MSW and fuel depletion, the study recommends a pyrolysis plant with of three-year payback period and an internal rate of return of 31%. On the other hand, MSW pyrolysis is environmentally friendly since it reduces carbon emissions and controls SOx and NOx emissions. Similar studies may have several gaps, some relating to the use of the simulation program, some to the actual pyrolysis process, and others to the raw material used. The composition of municipal solid trash is unstable in our country, where sorting is not given any importance, and even a small change in composition can affect the results. However, since the pyrolysis of municipal solid waste is a complicated process that is influenced by various variables in a synergistic manner, a more extensive examination is required. It should be mentioned that Aspen Plus is a precise program, especially for the pyrolysis process. This implies that the application occasionally fails to go to the next step due to errors caused by even the smallest user input error. The creation of a large number of equations and factors is also required.



Error! Reference source not found.: Block diagram illustrating the pyrolysis process’s mass and energy flows

X. RECOMMENDATIONS

Our research topic leads us to a number of recommendations for the future, including enhancing catalytic pyrolysis, examining MSW pyrolysis with different feedstocks, and carrying out more studies on the factors of the pyrolysis process. In order to get more accurate results, it is also recommended to use more challenging equations in the software simulation. It would also be helpful to conduct experimental testing, promote garbage sorting, and examine MSW pyrolysis at different transfer sites.

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