Heliyon 10 (2024) e24176

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Modeling and simulation of Khat waste fast pyrolysis for energy recovery

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ARTICLE INFO

Keywords:
Heating value
Net-energy
Aspen plus
Energy efficiency

ABSTRACT

Bioenergy is now recognized to be capable of providing the vast majority of predicted future renewable energy supply. Biomass is currently considered a common and commonly used renewable energy source. This study depends upon the investigation of khat waste using Aspen Plus software, which is required for creating environmentally friendly energy sources capable of improving our access to energy and economic sustainability. The outcome of the study is to understand the characteristics of the pyrolysis process without conducting a time-consuming, expensive, and complex procedure. The results of the investigation will be useful in determining the best feedstock for the formation of biofuel. Aspen Plus software simulates several ash-free organic components, including carbon, oxygen, nitrogen, hydrogen, and sulfur, with results like 45.72 % for carbon, 5.84 % for hydrogen, 0.43 % for nitrogen, and 38.56 % for oxygen. The production of biofuel is affected by processing parameters such as temperature and total mass flow rate. During reactions with the same mass but different temperatures, the bio-oil declined from 600 °C to 800 °C, while the maximum gas emission climbed quickly and the biochar reduced. In addition, it was recovered from Khat waste and proved to have an energy efficiency of 80.75 % and a net energy capacity of 134.25 kW. In addition, the High heating value (HHV) can be obtained from Khat waste is 19.38 MJ/kg, and low heating (LHV) can be 18.12 MJ/kg. We have been able to realize it using the Institute of Gas Technology formula based on ultimate analysis. The results show that Khat produces more oil than other wastes. As a result, all Khat waste is naturally occurring and Khat waste usually contains less nitrogen and no sulfur when used as fuel, which is an air pollutant reducing and protecting the environment.

1. Introduction

1.1. Background

Due to the depletion of crude oil, which is brought on by rising demand for oil and its derivatives due to newly created economic and environmental burdens caused by fossil fuels, finding alternative energy, fuel, and chemical production methods has gained attention [1]. Until recently, the world relied on biologically produced energy to meet its heating demands. Following coal and oil,

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https://doi.org/10.1016/j.heliyon.2024.e24176
Received 6 May 2023; Received in revised form 18 December 2023; Accepted 4 January 2024
Available online 17 January 2024
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biomass is the world's third most common and important energy source [2,3].

Petroleum oil, natural gas, and coal are the main forms of nonrenewable fossil fuels used to generate energy around the world [4]. Nevertheless, such fuels include the release of carbon dioxide (CO2), It increases the adverse effects of releases of greenhouse gases, leading to climate change and global warming [5,6]. The leading causes of a lack of foreign currency are the depletion of fossil resources and their fluctuating prices, particularly in developing nations without petroleum reserves like Ethiopia. The manufacture of liquid fuel from a renewable resource will be of significant interest due to the rise in global energy needs, as well as the high cost of petroleum and natural gas the effects of climate change, and the predicted future reduction in the supply of fossil fuel feedstock. Ethiopia, one of the emerging countries, lacks oil reserves and is short on foreign currency. Ethiopia does, however, have numerous sources of renewable energy [7–9].

It anticipated that biofuel produced by pyrolysis biomass would substantially impact the prospective energy supply [10]. Bio-oil has a higher density than other raw biomass, making transportation and storage easier. Biofuel has emerged as a viable choice for reducing petroleum consumption, which is now sold at exorbitant prices and raises concerns about energy protection and global climate change [11]. Biofuel is utilized in transportation and cooking and has a global use, particularly in rural parts of underdeveloped countries such as Ethiopia. These biofuels have the potential to significantly improve the health of billions of people [12,13]. This study used the above-mentioned software to analyze the burning of khat waste to calculate liquid fuel yield as well as net energy generated by the pyrolysis of khat waste [14]. Factors that affect liquid fuel production in the Aspen plus software and pyrolysis process will be studied. By simulating the yield result of bio-fuel from feedstock characteristics such as ultimate analysis of khat waste obtained from the experiment, using Aspen Plus tools [15].

Using this modeling process, the calorific values of waste pyrolysis were determined. The energy efficiency of khat and the net energy contents of pyrolysis must be determined. This study aims to produce biofuel from biomass, and One of the emerging nations with a financial imbalance is Ethiopia [16]. Lack of foreign currency results from the depletion of fossil fuels and their fluctuating prices, especially in developing nations without petroleum reserves. The development of biofuels will be highly sought after due to rising energy demand, high fossil fuel costs, global climate change, and anticipated future reductions in fossil fuel feedstock [17–19].

We can use this waste to improve and save our country from foreign currency. The usage of this software in process engineering has now commonplace in the past few years, sophisticated arrangements for process engineering, and used to access all biological characteristics.

The study's purpose was to improve bio-oil yield by maximizing the pyrolysis procedure operational variables such as mass flow of feed and temperature. The results of the model and the laboratory tests proved to be within acceptable alignment, demonstrating that the simulation model can be utilized for estimating pyrolysis output [20]. The simulation findings also show that Aspen Plus can be used to optimize the pyrolysis operating settings and that the results can be put to use for experimental testing. In this simulated study, the composition of the biofuel produced by pyrolysis of khat wastes is also estimated. The research will allow us to understand the process's behavior without having to conduct time-consuming, expensive, and difficult trials [21]. The results of the investigation will be useful in determining the best feedstock for the formation of biofuel.

2. Materials and methods

2.1. Introduction

Aspen Plus is a simulation and modeling software program. This software is utilized to simulate initial pyrolysis and anticipate the output products of biofuels such as char, bio-oils, and syn gases. Interactions with the solid, liquid, and vapor phases can be managed using Aspen Plus models. The majority of model development is known as a block as the material changes its various physical and chemical processes [22,23]. Generally, the Aspen Plus model block is divided into three bases: balanced, equilibrium, and kinetic. Balance-based examples include (RYield and RStoic); equilibrium-based examples include (REqual and RGibbs); and kinetic-based examples include (RCSTR, RPlug, and RButch). The RStoic block (DRYER) requires that the amount of water removed occurs and accepts moist biomass, name feed, and dryer phase simulation as inputs [20]. The simulation created a reactor model by integrating the RYIELD and RGIBBS reactors. The second block, DCOMP or RYield, requires dried Khat or DRIEDPROD and is used to yield product and decompose feedstock into the component of choice at fixed temperature and pressure.

2.2. Process flow sheet

It starts by using a drier block running at 150 °C, to eliminate any excess water from the sample of Khat waste biomass. The dried stream was fed into the breakdown block (DCOMPOSE), which was designed to resemble a yield reactor. It converts the raw material to standard simulated elements (water, ash, cellulose, hemicellulose, and lignin) based on proximate and chemical information. The biomass has been converted into conventional constituents according to the final examination of khat waste by formulation of calculation unit based on the final analysis of khat waste by formulation of calculation unit. Chemical compositions were determined using the dried reactor streams by minimizing Gibb's free energy at the set temperature. The cooler brought the temperature down and created a liquid/vapor combination from which syngas and bio-oil were separated. In contrast, a solid separator was used to separate the ash portion from the char in the solid stream. In this block, the RGIBBS (Gibbs) reactor calculated the chemical and equilibrium state [24,25]. Stoichiometric formulae aren't needed in ASPEN Plus version 8.8 for the Gibbs reactor or the product change reactors. The specification entered was used to provide information on the feedstock and simulation environment, and it was provided as calculation techniques during the Aspen Plus program simulation. Three different reactor model types are used to develop the model and the block name, brief explanation, and block ID of the model are shown in (Table 1) [26].

MIXCINC's general flow category for the simulation has been set to CISOLID (conventional solid), MIXED (liquid and vapor), and non-conventional solid (NC). Many assumptions are made in this simulation to conduct this investigation. In the simulation model Aspen Plus v8.8, pyrolysis is isothermal and has a steady state [28]. Because the model is not transitory or changing, times-dependent functions such as heating rate and time of residence cannot be explored explicitly. To be used for proper time studies, the model must be transferred to ASPEN plus Dynamics, a different but related software tool. Particle size is also not considered in this simulation because the PSD of Khat waste does not impact the amount of energy produced by burning biomass. The percentages of moisture in biomass are represented by the water content or indications of water vapor in the produced gas envelope. The proximal, ultimate, and sulfur analyses are all simulated using DCOALGEN and HCOALGEN, and the stoichiometric equation evaluates the density and enthalpy of municipal solid waste [20]. The cooling process decreased the temperatures, resulting in a liquid/vapor mixture from which syngas and bio-oil were extracted. The solids stream, on the other hand, solid separator, where both the char and ash fractions are separated. The simulation model for this Aspen Plus scenario is shown in (Fig. 1).

The R-stoic or dryer block will update the proximate result entered at the beginning of the simulation, and the first calculator block defines the moisture contents that are output by using Eqs. (1)–(3) [28].

$$Khin * \frac{H2O_{in}}{100} = Kh_{out} * \frac{H2O_{dr}}{100} + Kh_{in} * CONV \tag{1}$$

$$Kh_{in} = Kh_{out} + Kh_{in} * CONV \tag{2}$$

where:

- ➢ Kh_{in} = Khat mass flow rate for wet-Khat
- ➢ Kh_{out} = mass flow rate of Khat in-stream dry product
- ➢ H_2O_{in} = percentage of the wet-Khat stream's moisture content
- ➢ H_2O_{out} = a dry goods stream's moisture content as a percentage in Khat
- ➢ CONV= Partial conversion of Khat to H2O.

$$CONV = \frac{H2O_{in} - H2O_{dr}}{100 - H2O_{dr}} \tag{3}$$

The following formula determines the yield of biofuel products as Eq. (4) [29].

$$Y_{Biofuel} = \frac{m_{biofuel}}{m_{kh}} * 100 \tag{4}$$

2.3. Heating value and energy potential from Khat waste

2.3.1. Higher and lower heating value

Determine the heating value of the given sample, which is 100 % Khat, using the elemental makeup of Khat waste, by using the Institute of Gas Technology (IGT) had to calculate the higher heating value of the sample by Eqs. (5) and (6) [30–32].

$$\text{HHV } (KJ / Kg) = 354.68(\text{C}) + 1376.29(\text{H}) - 15.92(\text{A}) - 124.69(\text{O} + \text{N}) + 71.26 \tag{5}$$

$$\text{LHV} = \text{HHV} - 218.13(\%\text{H}) * (3.16) \tag{6}$$

in this situation, HHV denotes a greater heating value or a high caloric value expressed in kilojoules per kilogram, which is obtained from the percentage compositions of elemental analyses of Khat waste. In this formula, all elemental compositions are expressed as a mass proportion.

Table 1
The Aspen Plus unit operations model block's description [27].

Aspen Plus Name	Block IDs	Description
R-stoic	DRYER	Take input dried wet Khat and remove water as called moisture
Splitter	Sep1	Split moisture from the dried feed
Splitter	Sep2	To separate ash from vapor
RYIELD	DCOMPOSE	It converts the feedstock to equipped simulation components (water, ashes, cellulose, hemicellulose, and lignin) based on proximate and chemical information.
RGIBBS	PYROLYSE	To calculate phases and chemical equilibria.
HEATER	COOLER	Separation of the char from the product vapor for the reduction of the vapor stream temperature to induce the Condensation of liquid products
FLASH 2	SEPARAT3	Separation of pyrolysis oil from non-condensable gases
CALCULATOR	CONVERT	By specifying the RYIELD mass, calculating moisture, and specifying the RYIELD mass, you may calculate the elemental composition of feed.

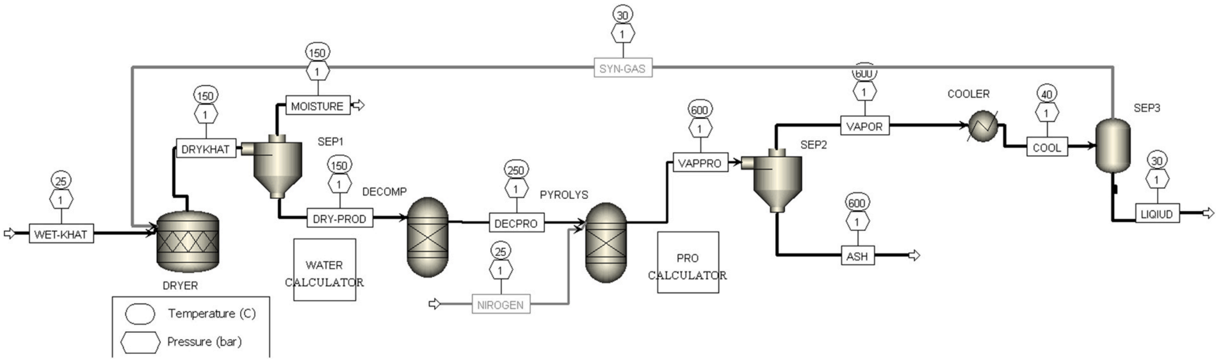

Fig. 1. Aspen plus simulation model.

2.3.2. Energy potential from chat waste and efficiency

Energy consumption during pyrolysis operations, such as drying energy, target energy, or pyrolysis energy consumption, has been utilized to calculate waste pyrolysis's energy efficiency and net-energy potential [33–35]. When placing Industrial waste into pyrolysis reactors, R-stoic can be used to dry it to reduce its moisture content. The given heat may be applied to increase the temperature of the feedstock and evaporate the water. Flue gas use generates sensible heat [34], raising Khat waste's temperature by causing some water to evaporate partially energy consumed determined by using Eqs. (7)–(10) [36,37].

$$Q_D = Q_S + Q_L \tag{7}$$

$$Q_S = m_w * c_{p,w} * (\Delta T) \tag{8}$$

$$Q_L = m_w * L_{sh} \tag{9}$$

$$Q_D = m_w * c_{p,w} * (\Delta T) + m_w * L_{sh} \tag{10}$$

where: $\mathbf{Q_D}$ is energy consumption for drying of khat waste $\mathbf{Q_S}$ is sensible heat, $\mathbf{Q_L}$ is water's latent heat, $\mathbf{m_w}$ is mass of moisture in kg/hr., $\mathbf{c_{pw}}$ is specific heat ratio of water, $\mathbf{L_{sh}}$ is the water's particular latent heat, And $\mathbf{\Delta T}$ is changing in temperature that is $\mathbf{T_2}$ from $\mathbf{T_1}$, where $\mathbf{T_1}$ is the temperature initial of khat entered, and $\mathbf{T_2}$ has also desired temperature of pyrolysis Chat waste.

Heating dry Khat waste to the pyrolysis temperature requires a certain amount of energy, known as the energy target, calculated using the following Eq. (11) [36,37].

$$Q_p = m_{kh,d} * c_{p,kh} * \Delta T \tag{11}$$

where: $\mathbf{Q_p}$ is the entire quantity of heat-dried khat waste required for pyrolysis, $\mathbf{m_{kh,d}}$ is the mass of dried khat waste in kilograms per hour, $\mathbf{c_{p,kh}}$ is the specific eat-to-dried khat waste ratio, and ΔT is temperature change from 105 ^{O}C to the time when pyrolysis began.

The power efficiency or energy of the Khat waste sample and the mass of khat used for pyrolysis are also used to compute the gross total energy of khat waste as Eq. (12) [35].

$$E_{Gt} = (m_{kh} - m_w) * HHV \tag{12}$$

where $\mathbf{E_{Gt}}$ = gross total annular energy, $\mathbf{m_{kh}}$ = mass of khat for pyrolysis in kg/hr., $\mathbf{m_w}$ mass of moisture removed, and HHV = caloric value of Chat waste.

Some energy is utilized in heat and dry chat waste in preparation for pyrolysis to evaporate water and ruin. The remaining portion is accessible for conversion to create useful work known as net energy calculated by Eq. (13) [37–42].

$$E_N = E_{Gt} - (Q_D + Q_P) \tag{13}$$

where: $\mathbf{E_N}$ net energy, $\mathbf{E_{Gt}}$ gross total energy from Chat, and $\mathbf{Q_D}$ and $\mathbf{Q_P}$ energy consumed for drying and heating pyrolysis, respectively.

The following formula Eq. (14) determines how much energy efficiency of pyrolysis khat waste [41,42].

$$\eta_{E,kh} = \left(\frac{E_N}{E_{Gt}}\right) * 100 \tag{14}$$

where: $\boldsymbol{\eta_{Ekh}}$ is the energy efficiency of pyrolysis Chat waste, $\mathbf{E_N}$ is net energy, and $_{\mathbf{EGt}}$ **is** total gross energy.

3. Result and discussion

3.1. Aspen plus simulation results of pyrolysis Khat waste sample

(Table 2) below illustrates how we utilized this program to vary the raw feedstock's temperature and mass flow rate to determine the elemental composition of Khat and the yield product of biofuel. The heating value, net energy, and efficiency of Khat have been calculated in considering the results.

The density and enthalpy of raw khat waste determined as Aspen plus software simulation results give −0.076 Gcal/h. And 1281.06 $kg/m^{3,}$ respectively. Also, the density of liquid fuel is 1.321 g/cm^3. This number derived from the elemental compositions of khat discarded is equivalent to the basic composition of this sample's variety of biomass and municipal solid waste [1]. When assessing the values of different literary works, such as those of carbon, hydrogen, Oxygen, nitrogen, and sulfur, 43.8, 6.2, 42.64, 0.44, and 0.09, respectively [40,43]. The final analysis refers to the essential elements of biomass, including C, H, N, O, and S. Compared to other components. Carbon appears to have a higher heating value; some carbon will exist as volatile matter, and some carbon will take the form of char. Hydrogen impacts the fuel's ability to heat up, and during pyrolysis, most of the hydrogen will be found in the volatile material.

Researchers studying different kinds of biomass produce diverse estimations of the elemental compositions of that biomass. Carbon, hydrogen, nitrogen, Oxygen, and sulfur have respective arrangements of 42.54, 6.25, 0.8, 38.68, and 0.23 [1].

The pyrolysis simulation of Khat waste is carried out by adjusting the condition from 500 °C to 800 °C and the total mass flow rate of 50, 75, and 100 kg/h as shown in (Table 3). The corresponding yields of syngas, liquid fuel, and biochar were calculated using simulations created by the Aspen Plus software package. The following (Table 4) displays the product yields based on the simulation.

In this simulation, the maximum liquid fuel production (35.04 %) obtained from the pyrolysis block temperature was 600 °C and a high total feed mass flow. The Aspen Plus software simulation also calculates the wet Khat feedstock's water loss or moisture contents and similarly determines the pyrolysis feedstock's feed density and enthalpy. The low amounts of liquid fuel produce the small mass flow of simulation and 800 °C. Pyrolysis gas product yield should be at a maximum of 37.322 % when pyrolysis temperature simulation at 800 °C with 50 kg/h of total mass flow rate.

The comparison of simulation findings with the experimental results (Table 5) offers feedback on the model's exactness. Generally, the results of past research [44] used the same kind of feedstock, although we did it with software simulation, they did it using experimental methods. The results we got are close but we were able to get more bio-oil. Because during experimentally the feedstock may be affected by problems such as environmental conditions and feedstock quality. In addition, the study of [24] also found very large bio-char and little gas, which when compared to ours we obtained more bio-oil from a temperature of 600 °C using fast pyrolysis. So raising and lowering the temperature can now change bio-fuel availability.

A) Effects of Temperature Simulation

From the ASPEN PUS simulation, the yield of tar oil increases from **500 °C** to **600 °C**, then decreases again above 600 °C. At 600 °C temperature and 100 kg/h of mass flow rate, liquid yield reaches a maximum of 35.04 % % as illustrated in (Fig. 2).

At 500 and 600° Celsius, the char output rapidly drops from 35.5 % to 28.5 %. Moreover, the temperature drops slightly from 600 (28.5 %) to 700 °C (27.89 %). At 800 °C, roughly 24.9 % of biochar is produced. The maximum biochar at a low temperature of 500 °C is 35.5 %. Gas product yield increases rapidly from 500 to 800 °C, from 24.8 to 35.65 %. The top gas product obtains the maximum temperature [44]. From this statement, to conclude that pyrolysis temperature increases, biochar decreases, but liquid fuel also increases starting at 500 °C to 600 °C, and when the temperature is above 600 °C, it also reduces again.

Similarly, an increased pyrolysis temperature reaction increases the gas yield product. At the same amount of mass but different temperature reactions, the bio-oil decreased from 600 to 800 °C. The maximum amount of biochar obtained and inversion and minimum amounts of gas yield gains [24], but the liquid product increased slightly at the temperature reaction reached 600 °C. Finally, maximum gas yield increased rapidly when temperature reacted, and biochar decreased.

B) Effects of Total Mass Flow

The rise in the mass flow rate with a spike in liquid fuel output grew first and subsequently decreased, implying that the amount of khat waste raised liquid fuel to temperatures above 600 °C. When the temperature exceeds 600 °C, it begins to decrease. From 500 °C,

Table 2
Ultimate results of Khat waste.

SI.no	Elements	Simulation Results (%)
1	*Carbon*	45.72
2	Oxygen	38.56
3	Nitrogen	0.43
4	Hydrogen	5.84
5	Sulfur	–
6.	Ash	4.61

Table 3
Amounts of bio-fuel obtained from Aspen Plus results in Kg/hrs at different values of temperature and mass flow rate.

Temperature ^{O}C	Total mass of feed kg/hrs.	Solid (kg/hrs.)	Liquid (kg/hrs.)	Gas (kg/hrs.)
500		**18.99**	15.52	12.55
600	50	18.701	**16.92**	13.95
700		18.4	15.05	14.135
800		13.2	14.32	**18.661**
500		**28.49**	23.285	19.463
600	**75**	27.6	**24.7**	19.99
700		23.21	24.1	24.042
800		20.46	23.8	**27.309**
500		**35.5**	33.6	24.8
600	**100**	28.5	**35.04**	25.62
700		27.39	33.29	26.89
800		24.9	32.7	**35.65**

Table 4
Yield products of bio-fuel ($Y_{bio\text{-}fuel}$) under Simulation of Aspen Soft-ware.

Temperature ^{O}C	Mass flow rate (kg/hrs.)	Solid yield,% (Y_{solid})	Liquid yield,% (Y_{liquid})	Gas yield,% (Y_{gas})
500		**37.98**	31.04	25.96
600	50	37.4	**33.84**	27.68
700		36.8	30.1	**28.27**
800		26.64	28.64	37.322
500		**37.91**	31.046	25.1
600	**75**	36.8	**32.93**	26.65
700		30.9	32.1	27.9
800		27.28	31.73	**36.4**
500		**35.5**	33.6	24.8
600	**100**	28.5	**35.04**	25.62
700		27.39	33.29	26.89
800		24.9	32.7	**35.65**

Table 5
Validation scheme.

Reference	Current study	Previous study [44]	Previous study [20]
Feed	Khat Waste	Khat Waste	Banana leaves
Temperature	600 °C	750 °C	500 °C
Bio-Oil	35.04	26	26.7
Bio-Char	28.5	47.2	57
Gas	25.62	26.8	6.3
Massf low rate	100 kg/h.		100 kg/h.

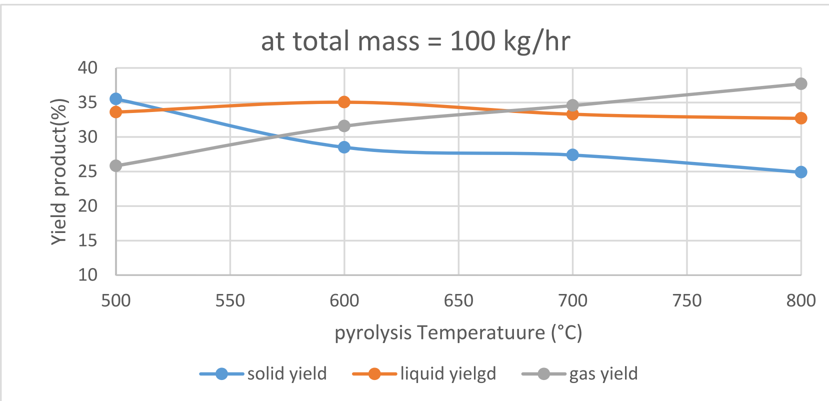

Fig. 2. Effects of Temperature Simulation on Product Yield under 100 kg/h Flow-rate.

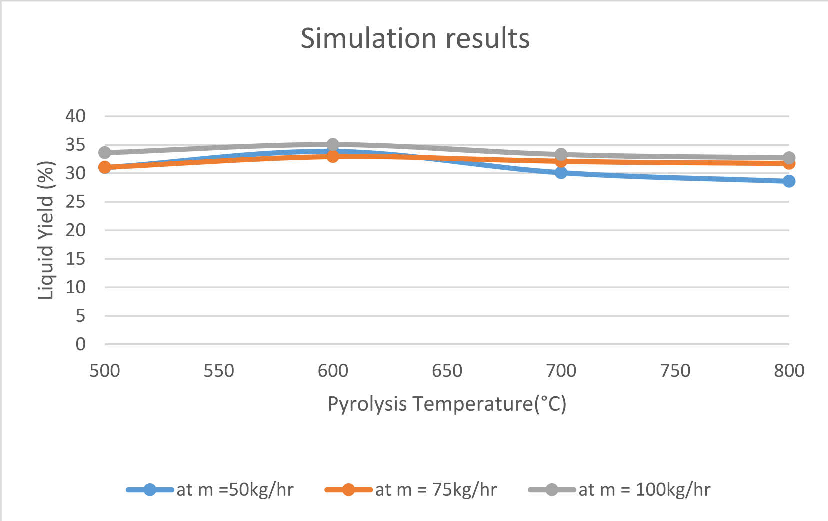

Fig. 3. Effects of flow-rate on liquid yield results.

the temperature of liquid fuel rises with the mass flow. A total flow rate of 100 kg/h, the maximum amount of tar (35.04 %) is produced (Fig. 3).

At a flow rate of 100 kg/h and a temperature of 500–600 °C, liquid yield increases significantly, gradually decreasing from 600 to 800 °C. Liquid product increased marginally from 31.046 % to 32.1 % at a mass flow rate of 75 kg/h and a temperature range of 500–600 °C. When temperatures rise over 600–700 °C, the yield does not vary (constant yield products), but when temperatures drop to 700–800 °C, it slightly decreases, resulting in 31.73 %.

When the total flow rate of the feed increases, the amount of biochar produced at 600 °C also increases. At 500 °C, a lower mass flow rate produces more biochar, while an enhanced mass flow rate leads to less. A rise in the flow rate accompanies a fall in biochar production as indicated (Fig. 4).

As the entire mass and rate of flow increased, the amount of gases produced decreased. At 600 °C, the total amount of feeds is 50, 75, and 100 kg/h, and the gas yields produced are 27.68, 26.65, and 25.62 %, respectively. At final reaction temperatures of 800 °C, the gas product yield is 37.322, 36.4, and 35.65 %, respectively, at mass flow rates of 50, 75, and 100 kg/h (Fig. 5).

3.2. Energy gained (heating values) of feedstock, energy consumption during pyrolysis, and net energy potential

This study calculates higher and lower heating values of Khat wastes to evaluate the potential energy contents of Khat biomass used during pyrolysis. Using the Simulation Analysis results in the fundamental or ultimate value of Khat, such as carbon content, oxygen contents, and hydrogen content, to obtain heating value [29,45]. The energy efficiency and net possibility of energy of pyrolysis khat refuse are calculated using outcomes of khat waste heating, the flow rate of Khat during pyrolysis simulation, and the moisture mass flow rate from dry khat garbage. When Khat waste is dried, water vaporizes and is removed, as represented by moisture using sensible heat, which increases feedstock and pyrolysis temperature [35]. In this simulation, some heat value consumed net energy, and efficiency was obtained from equations (5), (6), (13) and (14) illustrated as (Tables 6 and 7) respectively.

The net energy potential and energy recovery as heat in Khat waste or energy efficiency determined from heating value and mass flow rate were 108.42 KW and 80.75 %, respectively [35]. The energy recovery from biofuel of Khat waste was higher than from banana leaves, cotton, cow manure, and microalgae [20, 51, 52].

4. Conclusion

A steady-state recreation model was created using ASPEN Plus v8.8 to estimate the pyrolysis product yields for Khat wastes. Fast pyrolysis results in a variety of yield products at various temperature ranges, including solids (char and ash), liquid fuel (bio-oil), and gas fuel. Using simulated findings from Aspen Plus, the impacts of temperature, feed mass flow rate, and feed product moisture content on pyrolysis yield products are examined and discussed. Energy consumed during the pyrolysis process, gross energy annular of khat waste biomass, net energy used for proper and power generation, and energy efficiency must be determined.

The simulation result indicates that the maximum liquid fuel yield occurred at 600 ^{O}C temperature and a 100 kg/h mass flow rate and increased the amount of Khat waste to increase liquid yield products. With the help of elemental analysis from Khat waste by which we estimate its low heating and high heating value, we were able to obtain the following results from our simulation: 45.72 % carbon, 4.61 % ash, 5.84 % hydrogen, 38.56 % oxygen, and 0.43 % nitrogen. Similarly, from ASPEN PLUS simulation results to obtain the HHV and LHV are 19.38 and 18.12 MJ/kg, respectively.

We were able to obtain the following results from our simulation: 45.72 % carbon, 4.61 % ash, 5.84 % hydrogen, 38.56 % oxygen,

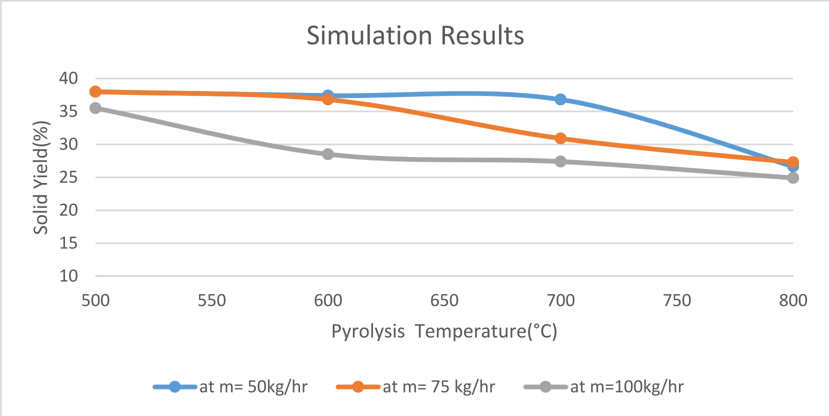

Fig. 4. Effects of flow-rate on solid yield results.

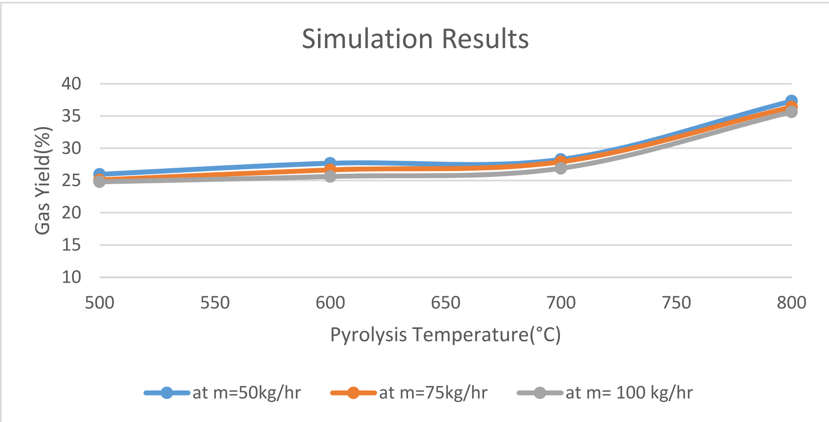

Fig. 5. Effects of flow-rate on gas yield results.

Table 6
Heating value analysis of pyrolysis Khat waste.

Feedstock	Higher heating value	Lower heating value
Khat waste	19.38	18.48

Table 7
Energy, and efficiency of pyrolysis Khat.

Total Energy type	Result (Value
Gross Energy (E_{Gt}) (KW)	134.25
Energy Consumed (KW)	25.56
Net Energy $E_{Gt} - (Q_D + Q_P)$ (KW)	108.42
Efficiency In Percent (%)	80.75

and 0.43 % nitrogen. Similarly, from ASPEN PLUS simulation results to obtain the HHV and LHV are 19.38 MJ/kg and 18.12 MJ/kg, respectively. This study investigates how agricultural waste, specifically khat waste in our area, can be used as fuel. It looked specifically at Khat's properties if converted to fuel biomass, which will reduce air pollution more than other biomass and clean up the environment that it is to preserve.

Data availability

The data that has been used is confidential.

CRediT authorship contribution statement

Geleta Afessa Moreda: Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Sorome Deresa Tolasa:** Investigation, Software, Validation, Writing – review & editing. **Debela Alema Teklemariyem:** Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e24176.

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