Acta. Chim. Asiana., 2022, 5(1), 181 –187
e-ISSN/p-ISSN 2550-0503/2550-049x
Available online at: www.aca.unram.ac.id

RESEARCH PAPER

Reaction Kinetics in the Pyrolysis of Human Hair Waste

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DOI: 10.29303/aca.v5i1.113

Article info:

Received 17/03/2022

Revised 06/04/2022

Accepted 08/04/2022

Available online 29/04/2022

Abstract: Human haircuts are a waste, and they can cause environmental problems. The human haircuts waste from barbershops has not been appropriately handled. This waste will be burned or just thrown away. Human haircut waste is difficult to decompose in nature, and the importance of environmental conservation, it is necessary to innovate in processing human haircut waste into beneficial products. This study investigates the reaction kinetics of gas formation in the pyrolysis of human hair cutting waste. The research method used is pyrolysis at high temperatures in the absence of oxygen in the system and the system under a vacuum. The pyrolysis of unwashed and washed human hair pieces follows a first-order reaction. The kinetics parameters of gas formation on the pyrolysis of unwashed human hair followed the Arrhenius equation with $K= Ae^{-9835.1}/RT$, and the activation energy was $81.769x10^3$ kJ/mol. Meanwhile, the gas kinetics on the pyrolysis of washed human hair followed the Arrhenius equation with $K= Ae^{-3667.1}/RT$ and the activation energy value of $30.487x10^3$ kJ/mol.

Keywords: Waste, Haircut, Pyrolysis, Kinetics, Gas

Citation: Anom, I. D. K., & Lombok, J. Z. . (2022). Reaction Kinetics in the Pyrolysis of Human Hair Waste. Acta Chimica Asiana, 5(1), 181–187. https://doi.org/10.29303/aca.v5i1.113

INTRODUCTION

Domestic waste, such as waste from household activities, business activities, restaurants, and offices, is waste that will never run out. This waste comes from the daily activities of people in general. Therefore, it is necessary to have good waste management and treatment mechanisms to not cause problems for the environment. Human haircuts are one of the domestic wastes from haircut businesses that must be handled properly. According to Kumar and Gupta, human hair pieces are considered a waste material in most societies. They are found in municipal sewage streams in almost all cities globally [1].

Human hairpieces that are considered useless are thrown away or burned. But it is not realized that the disposal and incineration of human haircut waste can disrupt environmental sustainability in water and soil. Burning of human hair cut waste in an open space can produce a foul-smelling gas, and directly or indirectly, this gas can interfere with human health and the environment. According to Vijayalakshmi and Malik, the improper disposal of waste human haircuts and other wastes in many of these units has been a source of pollution and legal conflicts [2]. Cohen also explained that with hair dust and rotting hair, workers from many human hair waste processing units in India have increased

cases of tuberculosis and respiratory infections [3]. According to Wenjing, the composition of hair consists of 51% carbon, 21% oxygen, 17% nitrogen, 6% hydrogen, 5% sulfur, and a small number of minerals [4]. Recognizing the importance of preserving the environment and human health, managing human hair cutting waste requires systemic thinking [5]. Therefore, technology to treat human haircut waste in the context of the need to consider all possible users and technologies and socio-economic and environmental impacts. Human hair is a common biological waste, and it can be pyrolyzed to prepare various types of functional materials [6]. Pyrolyzed hair has been used in various forms of traditional medicine. Szynkowska has researched human hair and discussed the content of various elements, including toxic metals (Ba, Cd, Pb, Sr) in adult hair [7].

Based on the description described previously, the treatment of human haircut waste is tried with pyrolysis technology. The pyrolysis technique is one solution to treat solid waste, especially human hair waste. Because of its easy working mechanism, the pyrolysis process does not produce new waste that can pollute the environment [8]. Another advantage is that solid waste pyrolysis will have a product with a high ratio and high energy content [9]. Pyrolysis techniques to treat solid waste, especially human haircut waste, must be developed continuously to obtain a good and efficient working system or mechanism. Therefore, the pyrolysis process of human haircut waste needs to be studied in depth regarding the decomposition process of substances during pyrolysis.

The decomposition of chemical compounds in the pyrolysis process is closely related to the chemical kinetics of substances, namely how time and temperature affect the amount of product produced. To accelerate the decomposition of substances and shorten the hydrocarbon chain can use a catalyst [10]. In addition, the use of a catalyst can increase the selectivity of the product based on what is desired [1]. It can increase the yield of the pyrolysis product [12]. Pyrolysis itself is a reaction that decomposes substances at high temperatures in a state of limited oxygen. The reaction goes through several stages: decomposition, gas formation, condensation, and the final stage or termination.

Pyrolysis of solid waste will produce products in liquids, gases, and the rest in the form of solids or charcoal. Researchers researching the pyrolysis of solid materials only examine liquid smoke and charcoal, while the resulting gaseous products are rarely studied, so that gas is wasted. Gases that cannot be cooled will be wasted in the air, so there is a need for research on the behavior of the gases formed in the pyrolysis process. Research that discusses the kinetics of gas resulting from the pyrolysis of human haircut waste is still lacking. Therefore there is a need for research on the pyrolysis of human haircut waste by investigating and applying gas kinetic theory, determining the reaction order, and determining the activation energy.

METHODOLOGY

Equipment and Materials

The tools used are electro-coat heaters, statives, clamps, condensers, round bottom flasks, glass tubes, measuring cups, glass pipes, thermometers, stoppers, scissors, and scales. The sample used in this study was the waste of unwashed and unwashed human hairpieces. The pyrolysis apparatus circuit is designed under vacuum and is shown in Figure 1.

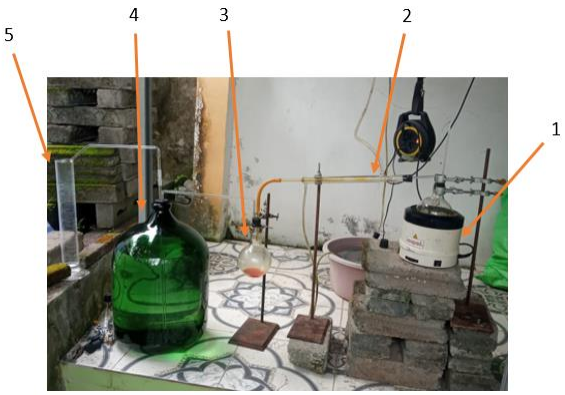

Figure 1. Pyrolysis Equipment Circuit.

1. Electro Coat, 2. Condenser, 3. Liquid smoke reservoir, 4. Gas reservoir, 5. Measuring cup for holding water

Procedures

The first pyrolysis is a sample of human hair (Figure2) cut waste without being washed. Weighed, as much as 200 g of unwashed human hair waste was slowly put into a round flask, and then the flask was tightly closed. Each connection in the pyrolysis device circuit is checked one by one until no gas leaks are found. Pyrolysis of human haircut waste is ready to start. Observations of the pyrolysis of human haircut waste were carried out on the gas products produced. The gaseous product formed is flowed into a large bottle filled with water (25 L). The gas forces the water into a large bottle then the volume of water flowing is accommodated in a measuring cup. The accommodated water volume is proportional to the volume of gas formed during pyrolysis. The volume of gas formed was observed every 15 minutes, and in addition, the pyrolysis temperature and pyrolysis duration were also observed.

Figure 2. Human Haircut Sample

The second pyrolysis is a sample of washed human hair pieces waste. Pyrolysis at the second point is carried out in the same way as at the first point pyrolysis.

RESULTS AND DISCUSSION

Pyrolysis

Pyrolysis of waste from human hair that has been treated without washing showed that the hair begins to melt at a temperature of 82oC. The formation of gaseous products also follows it. They are accommodated in the bottle and can be proven by the presence of flowing water and accommodated in a measuring cup. From the 75th minute to the 210th minute, it can be observed that the pyrolysis temperature of human haircut waste is almost constant at a temperature of 173 oC. It means that the pyrolysis system at a temperature close to constant we call the isothermal process. The volume of gas formed from pyrolysis of human haircut waste was observed within 15 minutes. The length of the pyrolysis process of human haircut waste is approximately 5 hours, and the total volume of gas produced is 9,030 mL. After the gas measurement ends, the gas is removed from the bottle employing a hole in the bottle stopper as large as a pinhole, and then the gas is burned. The gas flame is as big as a candle flame with a clear yellowish flame. It is predicted that the gas from the pyrolysis of human haircut waste is short-chain hydrocarbon compounds or compounds classified as methane gas. The gas can be used as an alternative fuel, such as LPG gas.

Table 1. Data of Gas Products from Pyrolysis of Human Haircut Waste

Unwashed hair		Washed hair	
Time (minutes)	Volume (ml)	Time (minutes)	Volume (ml)
15	1320	15	2480
30	1250	30	1100
45	1000	45	1100
60	1170	60	740
75	980	75	700
90	750	90	640
105	600	105	600
120	230	120	520
135	230	135	440
150	280	150	290
165	210	165	290
180	200	180	240
195	150	195	270
210	140	210	230
225	120	225	230
240	110	240	210
255	100	255	215
270	100	270	180
285	60	285	100
300	30	300	40
Total	9.030	Total	10.615

Pyrolysis of waste human hair has been washed first and then dried in the sun. In the pyrolysis process, it can be observed that the haircut begins to melt at a temperature of 80oC. From the 75th minute to the 210th minute, it can be observed that the pyrolysis temperature of human haircut waste is almost constant at 170oC. The pyrolysis system is isothermal. The length of the pyrolysis process of human haircut waste is approximately 5 hours, and the total volume of gas produced is 10,615 mL. The gas formed can burn completely, and it is proposed to be used as alternative fuel gas.

The longer the pyrolysis process is carried out, the amount of gas formed per unit time decreases, but the total gas product obtained increases. The decomposition of chemical compounds from large molecules into smaller molecules is also reduced. In the end, no more gaseous products are formed, so the pyrolysis process must be stopped. In addition to getting pyrolysis gas products, human haircut waste also produces products in the form of liquid smoke and charcoal.

Reaction Order

Based on the observation that gas formation in the pyrolysis of human haircut waste with an interval of 15 minutes, the gas fraction can be obtained as shown in Table 1. The observed data were processed using the graphical method in MS Excel to obtain a line equation curve. The form of the line equation obtained in each pyrolysis process is then matched with the integrated rate equation formula to determine the most suitable reaction order [13].

Table 2. Table of Integrated Rate Equations

Orde	**Line Equation**
Orde 0	$[\mathrm{A}] = -k\mathrm{t} + [\mathrm{A}_0]$
Orde 1	$\ln[\mathrm{A}] = -k\mathrm{t} + \ln[\mathrm{A}_0]$

The following is a line equation curve of each pyrolysis of human haircut waste shown in Figure 3 and Figure 4.

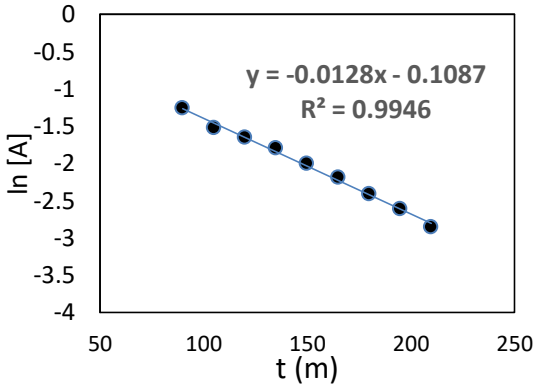

Figure 3. The Linear Equation Curve of Pyrolysis Gases From Human Haircut Waste Without Washing.

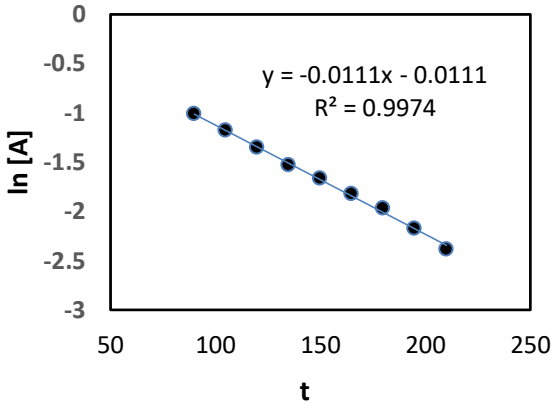

Figure 4. The Linear Equation Curve of the Pyrolysis Waste Gas from Washing Human Hair.

The reaction order can be studied by observing the R square (R2) of each line equation in Figures 3 and 4. The values of R2 = 0.9945 and R2 = 0.9974 are obtained. The two R2 values are close to 1 (one). The line equation whose R2 value is closest to the value of 1 is the most suitable line equation for determining the reaction order [14]. Thus, it can be concluded that the most suitable line equation curve from Figure 3 and Figure 4 is the gas formation curve following a first-order reaction. This means that if the gas concentration is increased, the reaction rate will also increase.

Activation Energy and Arrhenius Equation

Activation energy is the minimum energy that must be reached for a reaction. The value of the activation energy itself can be determined through an experiment. From the pyrolysis experiment of human haircut waste, data on volume changes every 15 minutes, as shown in Table 1. The gas volume data resulting from the pyrolysis of human haircut waste were processed to determine the reaction rate constants. The formula used is as follows [15]:

$$\frac{dml}{dt} = \mathrm{K}.f(\frac{ml - mla}{mlo - mla})$$

The value of dml is the change in volume, dt is the change in time, ml is the volume at time intervals, while mlo is the initial volume, and mla is the final volume.

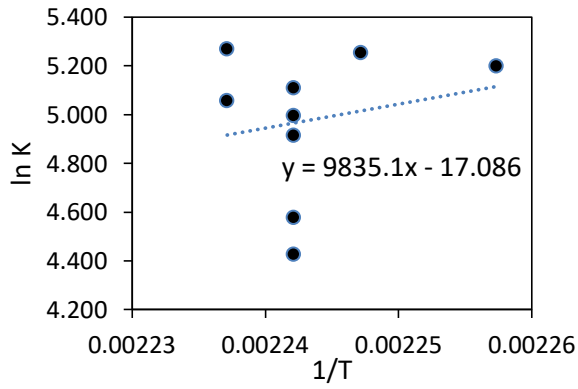

Figure 5. Line Equation of Pyrolysis Gases of Waste of Human Haircut without Washing, Plot ln K against 1/T.

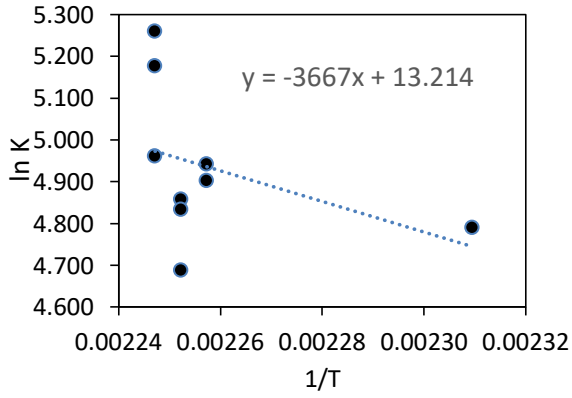

Figure 6. Line Equation of Pyrolysis Gases from Washed Human Haircut Waste, Plot ln K against 1/T

Based on the value of the constant obtained at each time interval, thus a plot of ln K against 1/T can be made. With the help of the MS Excel program, the line equation for each pyrolysis of human haircut is shown in Figures 5 and 6.

The line equations in Figure 5 and Figure 6 are included in the Arrhenius equation in a linear form with a slope of -Ea/R with a point of intersection of ln A o determine the value of the activation energy (Ea) [16].

$$\ln k = \left(-\frac{\mathrm{E}_a}{\mathrm{R}}\right)\left(\frac{1}{\mathrm{T}}\right) + \ln A$$

The value of the activation energy of each pyrolysis can be obtained. The relationship between the rate constant and temperature in pyrolysis can be seen in the Arrhenius equation. T is the absolute temperature Kelvin (K), R is the gas constant (8.314 J/K.mol), and A is the collision factor.

$$\mathrm{K} = Ae^{-\mathrm{Ea/RT}}$$

Haryono explained that a reaction could occur if the kinetic energy of the reactants exceeds the activation energy [17]. The difference in the activation energy values of the two gases resulting from the pyrolysis of human haircut waste can be caused by impurities such as dust or hair color paint that sticks to the surface of the hair, especially unwashed hair. The treatment carried out on the washed waste of human hair can reduce the value of the activation energy. It can be interpreted that by decreasing the activation energy, chemical reactions will be able to run faster, and the total gas product obtained is also more. Moreover, if the research on the pyrolysis process involves a catalyst, it may be able to reduce the activation energy more significantly when compared to pyrolysis without a catalyst. The use of a catalyst in the pyrolysis process will reduce the reaction temperature. The catalyst can affect the pathway of the chemical reaction mechanism according to the catalyst used [18].

Table 3. Activation Energy Values and Arrhenius Equation of Pyrolysis Gases of Human Haircut Waste

Human Haircut Waste	Temperature (K)	*-Ea/R*	E_a (kJ/ mol)	Rate Constant Exponential Equation .(minute^{-1})
without washing	446	9.835,1	81.769,021	$K = Ae^{-9835,1/RT}$
Washed	443	3.667	30.487,438	$K = Ae^{-3667/RT}$

CONCLUSION

Based on the results of research conducted on the pyrolysis of human haircut waste, it can be concluded as follows:

1. Pyrolysis of human haircut waste produces gas, liquid smoke, and charcoal.
2. Pyrolysis of waste human hair pieces without washing and washing turns out that both follow a first-order chemical reaction.
3. The kinetics parameters of gas formation in the pyrolysis of human hair waste without washing follow the Arrhenius equation with K= $Ae^{-9835.1}$/RT and the activation energy value (Ea) of 81.769 x 103 kJ/mol. The pyrolysis of washed human hair waste followed the Arrhenius equation with K= Ae-3667.1/RT, and the activation energy value (Ea) was 30.487x10^3 kJ/mol.
4. Pyrolysis of washed human haircut waste was found to reduce the activation energy value, which was quite significant compared to pyrolysis of unwashed human haircut waste, and the pyrolysis decomposition reaction would be able to run faster and produce more gas products.

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