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Synthesis of NiO/Zeolite Catalyst and Its Performance in Renewable Biomass Gasification Electric Generator

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Abstract

Research on NiO/Zeolite catalytic biomass gasification to produce electricity has been completed. This study aims to study the effect of the NiO/Zeolite catalyst on the voltage and current generated in the gasification process. This research was carried out by making NiO/Zeolite catalysts using the wet impregnation method, followed by contructing a gasification device plus installing a batch of catalysts in the reactor, and then testing the electrical parameters produced by the gasification equipment. The results obtained are NiO/ Zeolite catalysts which have been successfully synthesized using FTIR spectral indicators and XRD diffractograms with the appearance of NiO and Ni peaks at angles of 2θ $28°$ and $63°$. The resulting catalyst was also reported to have succeeded in increasing voltage stability compared to the gasification process without a catalyst with a maximum value of 250 V and an average value of 225 V. The NiO/Zeolite catalyst also succeeded in increasing the current value and stabilizing the current value compared to the non-reaction gasification process with a maximum of 50 A and an average of 44 A.

Keywords:gasification; catalyst; zeolite; NiO/Zeolite; power generator; renewable

INTRODUCTION

The potential for alternative fuels originating from organic material waste continues to be developed at this time to meet the increasing energy needs of the world community. This is done because organic materials have one major advantage over fossil fuels, namely their renewable potential (Sriram & Shahidehpour, 2005). Organic materials developed as alternative fuels can be sourced from animal materials(Manyi-Loh et al., 2013) or vegetable materials (Anggono et al., 2017; Sharma et al., 2015) either in solid, liquid or gas form. Both are still being studied and developed to obtain alternative fuels with performance close to or better than fossil fuels.

Several organic material wastes that have been studied as alternative fuels come from solid materials (Anggono et al., 2017; Wang et al., 2015). This solid organic material is known as biomass. Biomass is everything that comes from living things and contains the main mass, namely carbohydrates. Decaying fruit is an example of biomass that has been developed as an alternative fuel, namely into a liquid bioethanol fuel (Iskandar & Siswati, 2012). Other solid materials include sawdust (Kiss et al., 2016), coconut shells (Sulistyani et al., 2015), corn cobs (Cantrell et al., 2014), and empty palm fruit bunches (Chow et al., 2008) has also been widely developed as solid fuels such as pellets, briquettes and charcoal briquettes.

Solid biomass has limitations in terms of energy efficiency used. This is because the results of burning solid biomass produce more heat than free energy. An effort needs to be made so that solid biomass can have a higher efficiency in producing free energy so that energy work can be done more efficiently.

One of the efforts to produce more free energy from biomass is through the process of converting biomass into a syn gas or synthetic gas in a gasification process (Puig-Arnavat et al., 2010). Synthetic gas is gas - gas which can be further reacted to produce a fuel gas. This synthetic gas is in the form of CO and H_2, which can further react to form methane gas (CH_4) as a fuel. This methane gas can then be reacted in the combustion chamber to produce energy. Synthetic gas can be produced through the cracking reaction of a biomass at a high temperature utilizing the heat generated from heating the biomass. This effort can produce higher efficiency in the utilization of biomass as an alternative fuel.

Increasing efficiency in producing energy can also be done by adding a catalyst. The catalyst used has specifications for cracking such as Cr, Cu, Pt metals or metal oxides such as NiO or PdO (Haryani et al., 2020). The catalytic ability can also be enhanced by the presence of a carrier medium made of porous materials such as zeolite, gamma alumina, or natural clay. Cracking assisted by embedded catalysts has a better product because the size distribution of the catalyst can be more even in the presence of a support.

The process of cracking biomass to produce synthetic gas or gasification assisted by a catalyst NiO/Zeolite can be a solution for using biomass as a renewable alternative energy. The process is carried out in a sealed container with a strict control as a gasification reactor. The synthetic gas produced can be directly put into the combustion chamber (carburetor) to produce energy which can also be used to power generators and generate electricity.

METHODS

Materials

The tools used in this study were a gasification tool set which was a modification of an oven ignition system owned by BriqCo company, a 220V generator with a maximum of 12000 W, and a carburetor (DongFeng, owned by Briqco company), a calcination furnace, a vacuum pump, an analytical balance, and a number of glassware.

The materials used in this research program are several biomasses, namely wood chips, coconut shells, and plant wastes, catalyst materials consisting of $Ni(NO_3)_2$ (Merck p.a.) as NiO precursor, N_2 gas as inert gas, and natural zeolite as catalyst support.

Catalyst Syntesis

As much as 250 grams of acid-activated zeolite was mixed into 1000 mL of 0.1 M $Ni(NO_3)_2$ solution. The mixture was then stirred, and allowed to stand for 3 days. Furthermore, the mixture was evaporated to obtain a wet filtrate, the filtrate was dried in an oven at 90° C for 1 day. The solid obtained was then calcined in a calcination furnace at 500°C in a N_2 gas environment for 2 hours. Furthermore, the catalyst solids were characterized using FTIR and XRD.

Construction of Gasification Reactor Batch

The oven ignition device owned by the Briqco company was modified in such a way with the addition of pipes and a batch of catalyst in the ducts. Then, iron pipes were made and connected from the reactor to the carburetor and from the carburetor to the electric generator. The catalyst is placed in a catalyst bed which is located in a batch of catalysts in the reactor. The design of the gasification device is shown in Figure 1.

Figure 1: Gasification Reactor

Catalytic Gasification Process

As much as 1500 grams of biomass was placed in the reactor tube and then the fire was lit to ignite the heating assisted by a vacuum pump. Perfect heating occurs when there is a bright red color in the reactor that lasts for 5 minutes. The reactor system is then closed and connected via pipes. After that, a gas test is carried out by igniting a fire near the pipe. The reactor was ready to be connected to the carburetor if flames appeared to burst from the pipes. After that, the reactor is connected to a carburetor which has been connected to an electric generator. The gasification process was carried out in conditions without and with a catalyst using a variety of organic biomass used. Electrical parameters in the form of voltage and current become quantitative parameters for measuring electricity produced from biomass.

RESULTS AND DISCUSSION

Characteristics of NiO/Zeolite Catalysts for Gasification Process Catalysts

One of the problems in the cracking process of long chain organic compounds is the emergence of tar products in solid form which interfere with subsequent processes. The catalyst plays a role in breaking down the tar product into products that can be used as fuel. With the presence of empty orbitals in metal catalysts or metal oxides, electrons in the products of organic compounds can be more arranged by filling in the empty orbitals of the catalyst and the reaction results can be more controlled than without the use of a catalyst.

The NiO/Zeolite catalyst besides playing a role in reducing tar, this catalyst also functions to accelerate the formation of syngas products produced during the gasification process (Li et al., 2017). NiO oxide is added to the zeolite in order to have a larger surface area with a more even distribution on the surface of the zeolite. In addition, the dispersion onto the surface of the zeolite also provides a Quantum Size Effect which can further enhance the performance of the NiO catalyst.

Zeolite used as a carrier needs to be activated first. The activated zeolite surface is carried out so that the interaction between the catalyst and the carrier becomes stronger so that the catalytic process takes place more effectively (Gupta et al., 2018). The carrier activation in this study was carried out by acid activation. Acid activation also functions as a cleaner for impurities on the pores and surface of the zeolite, so that the zeolite becomes more active as a carrier as well as a catalyst.

Figure 2 shows the FTIR (Fourrier Transform Infra Red) characterization of zeolite, activated zeolite, and zeolite that has been impregnated with NiO. In the Zeolite FTIR spectra, there is a wave number of 3626.17 cm^{-1} indicating the presence of stretching vibrations of the -OH groups in the Al-O-H (aluminol) and Si-O-H (silanol) bonds. The wave number of 3425.58 cm^{-1} indicates the stretching vibration of the OH groups of the H_2O molecules in the zeolite pores. Likewise the absorption band at 1635.64 cm^{-1} which shows the bending vibration of the H-O-H of the adsorbed H_2O molecule. The Si-O group was identified by the appearance of a strong absorption band at 1033.85 cm^{-1} Zhirong et al. (2011).

Figure 2: FTIR Spectra of Zeolite, Activated Zeolite, & NiO/Zeolite

The wave number of 918.12 cm^{-1} shows the bending vibration of the hydroxyl group of Al-OH-Al. The wave number of 794.67 cm^{-1} shows the Al-Mg-OH vibration, the absorption band at that wave number shows a mixture of quartz in zeolite Yang et al. (2010). The wave number of 524.64 cm^{-1} shows the bending vibrations on Si-O-Al and Si-O-Si.

The activation process using HCl solvent does not change the functional groups in the zeolite. Each spectra has almost the same absorption peaks, but there are several absorption peaks that experience a shift in wave number. This happens because the metals contained in the zeolite framework dissolve in acids. There is a shift in wave numbers from 3425.58 cm^{-1} to 3433.29 cm^{-1} which indicates the OH stretching vibration of H_2O. Furthermore, the number 1033.85 cm^{-1} shifts to 1042.56 cm^{-1} which indicates the bending vibration of Si-O. The increase in wave number is caused by acid dealumination in the zeolite framework structure, namely the release of Al3+ in the structure Hidayat & Nugraha (2018). This is reinforced by the decrease in the intensity of the wave number 918.12 cm^{-1} in the activated zeolite which is the bending vibration of the OH group in Al-OH-Al. The acid dealumination process in zeolite can increase the Si/Al ratio. The wave number of 524.64 cm^{-1} which is a stretching vibration of Si-O-Al experienced a wave shift to 532.35 cm^{-1}.

The FTIR spectrum in Figure 2 did not show significant changes between acid activated Zeolite and activated Zeolite after impregnated with Nickel metal. The change that occurs is the loss of the wave number

3618.46 cm^{-1} which is the vibration of the OH group in the Al-O-H bond. This shows that there is no change in the structure of the zeolite due to calcination and impregnation treatment. This also shows that the zeolite framework structure has a fairly high stability.

The difference between acid activated zeolite and activated zeolite impregnated with Ni and NiO can be observed by means of XRD instrument. The XRD diffractogram can identify the minerals contained in a material through angle and basal spacing analysis through Bragg's law. The results of the material XRD can be observed in Figure 3.

The NiO/Zeolite XRD diffractogram has a peak at $2\theta = 19.60°$ with $d = 4.5293$ Å which indicates montmorillonite mineral. At this peak there is an increase in the value of d, namely the distance between the planes (basal spacing). The impregnation process will result in the expansion of the space between the sheets or the distance between flat plane activated NiO/Zeolite and the formation of a good pore system. A good pore system will result in an increasingly open surface of the acid-activated zeolite so that the specific surface area increases.

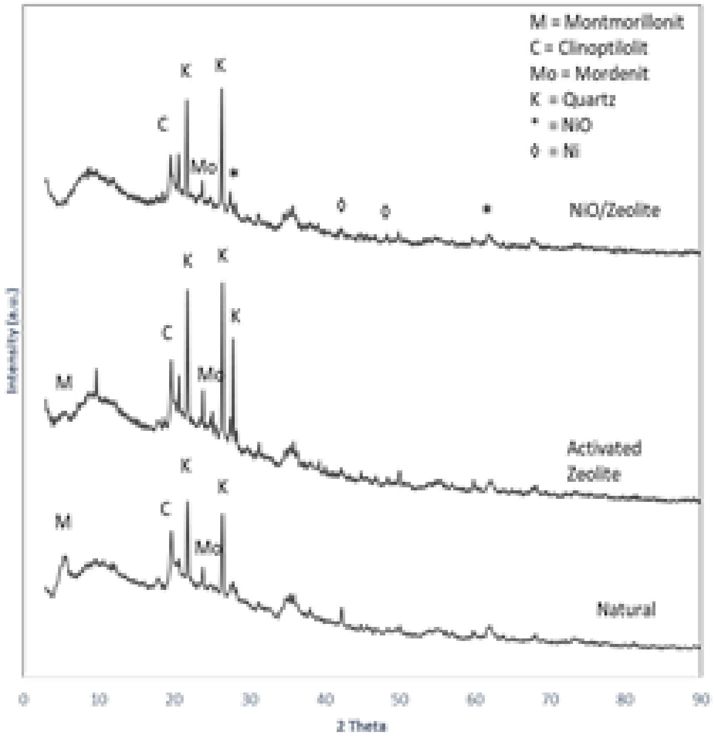

Figure 3: Diffractogram Pattern of Zeolite, Activated Zeolite, & NiO/Zeolite

The increase in basal spacing is also an effect of nickel metal expansion in the space between layers of the zeolite structure (Fatimah & Utami, 2017). Likewise the angle $2\theta = 20.64°$ ($d = 4.3034$Å), $2\theta = 27.52°$ ($d = 3.2412$ Å) which experiences a 2θ shift and an increase in the inter-basal spacing. The decrease in peak intensity at $2\theta : 9.72°$ and $2\theta = 27.90°$ occurs because there is a decrease in surface area, pore volume and a shift in the distribution of zeolite pore diameters which are thought to have NiO minerals covering the surface Al Anshori et al. (2009).

The character of NiO on the identified catalyst appears at an angle of 2θ $28°$ and $63°$ which is also supported by the appearance of metallic character Ni at an angle of 2θ $42°$ and $49°$. This indicates that the impregnation process has succeeded in loading NiO and also Ni into the pores of the zeolite structure. With this indication, the NiO/Zeolite catalyst has been successfully synthesized and is ready to be applied in the gasification process.

Electrical Parameters Generated by NiO/Zeolite Catalyzed Gasification Equipment

The prepared NiO/Zeolite catalyst is put into the gasification reactor. Laying the catalyst in the gasification reactor has the intention that the gasification process can take place more quickly and the by-products in the form of tar can be directly decomposed in the presence of a catalyst.

Electrical parameter measurements were carried out on the gasification process of a random mixture of biomass. The amount of biomass used in the gasification process in the reactor is 1.5 kg according to the maximum capacity of the reactor. The combustion process in the reactor is assisted by a vacuum pump to draw oxygen from outside the reactor. The result of burning biomass in the reactor is syngas which is used as fuel to produce electricity.

The resulting syngas product passes through several channels to remove tar which is still carried in the gaseous state. The syngas product that is formed is fed into the carburetor to be reacted with oxygen from the air so that it drives the dynamo on the generator to produce electricity. The parameters of voltage and current are the parameters measured in this test.

Figure 4 shows the voltage generated from the gasification device in a function of time. The voltage measurement is directly read on the generator display screen in units of Volts. The relationship of the voltage generated from the gasification product to the function of time is shown as follows.

The results show that there is a change that occurs between the electricity generated from gasification products without a catalyst and with a catalyst. Gasification products without a catalyst have a maximum voltage value between 210 – 230 V and decreases over time. The voltage drop is due to reduced syngas which reacts in the carburetor which causes the energy produced by the generator to also decrease.

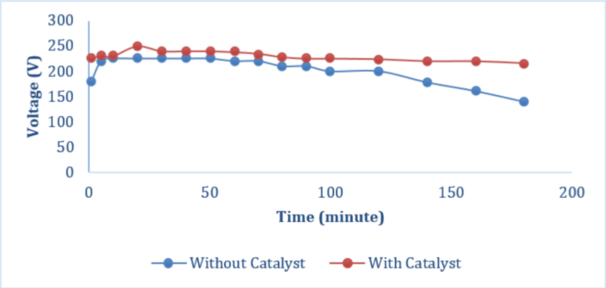

Figure 4: Graph of Voltage Relationship resulting from Gasification Products to Time Function

The results show that there is a change that occurs between the electricity generated from gasification products without a catalyst and with a catalyst. Gasification products without a catalyst have a maximum voltage value between 210 – 230 V and decreases over time. The voltage drop is caused by reduced syngas which reacts in the carburetor which causes the energy produced by the generator to also decrease.

The voltage value generated by gasification with a catalyst has better stability than the gasification process without a catalyst. The resulting maximum value is 250 V and is stable in the range of 220 V to 180 minutes. This shows that the catalyst has a role in increasing the efficiency of the syngas product produced through an additional mechanism, namely converting tar into syngas.

The current value generated by the gasification product is shown in Figure 5 The value of the current strength resulting from the gasification process with a catalyst has a better value than the gasification process without a catalyst. The gasification process with a catalyst produces a maximum current strength of 52 A with a value that lasts above 40 A for up to 180 minutes. In contrast to the strong current generated by gasification products without a catalyst. The maximum value produced is only 40 A with a value that continues to decrease to 30 A at the 180 minute measurement.

These two parameters show that the NiO/Zeolite catalyst is able to stabilize the voltage value generated by the generator and also provides a better current strength than the gasification process without a catalyst. The mechanism for increasing this value is based on the ability of the catalyst to change the by-products in the form of tar into syngas products which also add value to the efficiency of the gasification process.

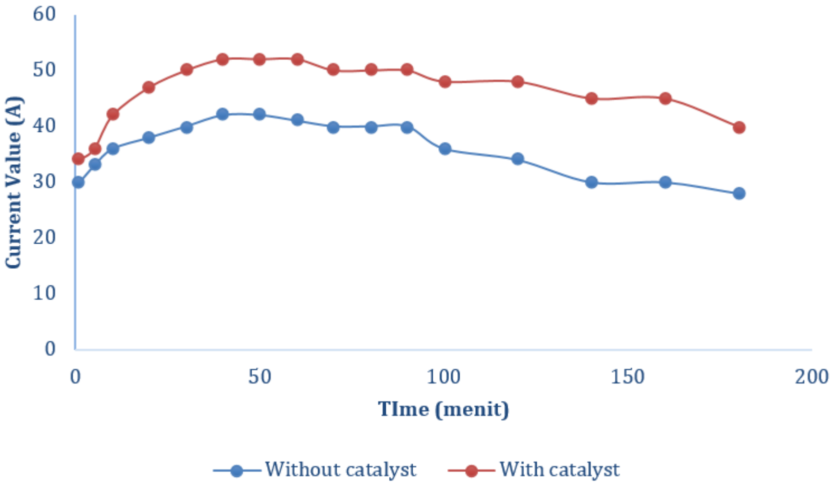

Figure 5: Graph of Current Value Relationship resulting from Gasification Products to the Function of Time

CONCLUSION

This work has shown that NiO/Zeolite catalyst has been successfully synthesized by wet impregnation method. The character of NiO appears in the XRD analysis which indicates that the process of embedding NiO into the zeolite was successful. The NiO/Zeolite catalyst increases the efficiency of the gasification process. The parameters of the voltage and current strength produced by the gasification apparatus show that the NiO/Zeolite catalyst has a significant effect on the value of the voltage and current strength as well as the stability of their values over a period of 180 minutes.

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