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EFFECT OF IRON (III) OXIDE, NICKEL OXIDE NANOPARTICLES AND THEIR BLEND ON THE YIELD AND QUALITY OF BIOETHANOL PRODUCED FROM CO-FERMENTATION OF RICE HUSKS AND BANANA PEELS

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Abstract-**Effect of Iron (iii) Oxide (Fe_2O_3), Nickel Oxide (NiO) nanoparticles (NPs) and their blends as biocatalysts on the yield and quality of bioethanol produced from co-fermentation of rice husks and banana peelshas been investigated. In this study, rice husks (RH) and banana peels (BP) were collected and prepared for characterization using proximate, ultimate and composition analysis techniques. Prepared samples were pretreated using acid pretreatment before enzymatic hydrolysis, co-fermentation and product analyses. Experiments were performed using the following blending ratios: 100wt.%RH:0wt.%BP, 70wt. %RH: 30wt. %BP, 50wt. %RH: 50wt. %BP, 30wt. %RH: 70wt. %BP and 0wt. %RH: 100wt.%BP. The Fe_2O_3 NPs, NiO NPs, and their blend (Fe_2O_3+NiO at 1:1) were added accordingly to sample blends. Untreated feedstocksamples without nanoparticles, butprepared using the same blending ratios, served as the control samples. Results revealed that the sample blend, 30wt. %RH: 70wt. %BP, treated with Fe_2O_3+NiO produced the highest yield of bioethanol (27.8 g/l). This could be associated with the combined effect of the nanoparticles and probably coupled with the co-fermentation effect of the blends of the two lignocellulosic biomass feedstocks. The least yield of bioethanol (23.2 g/l) was produced from the untreated sample blend, 100wt. %RH: 0wt. %BP, that contains only rice husks. The untreated sample blend, 0wt.%RH:100wt.%BP, containing banana peels alone gave a higher bioethanol yield (25.6 g/l) than sample blend with only rice husks, probably due to higher content of fermentable sugars and lower lignin level in banana peels than in rice husks. Bioethanol yields from feedstock samples treated with Fe_2O_3, NiO and Fe_2O_3+NiO NP respectivelywere observed to increase withthe increasing weight percentages of banana peels in the blends.The feedstock samples treated with $Fe_2O_{3\ NPs}$ gave higher yields of bioethanol than samples treated with NiO NPs alone. This suggested that$Fe_2O_{3\ NPs}$ is a better catalyst than NiO NPs in this specificreaction, enhancingenzymatic activities that facilitate conversion of sugars into bioethanol.**

Keywords: **Bioethanol production, Effect of nanoparticles, Co-fermentation, Rice husks and Banana peels, Enhanced yield and quality**

I. INTRODUCTION

Fossil fuels are the major source of energy worldwide. However, the use of fossil fuels is associated with global warming, climate change, and a variety of energy and security problems.Consequently, alternatives to these fossil fuels are being explored with biofuels being one of them. Biofuels are eco-friendly, carbon neutral, and available for energy security [1], [2], [3]. The importance of liquid biofuels (bioethanol and biodiesel) is increasing globally due to the rising concerns about oil security and climate change. Bioethanol is a renewable and environmentally friendly energy source typically produced through the fermentation of organic materials, primarily from crops rich in sugars or starches such as corn, sugarcane, and wheat (first generation feedstocks). The use of these first-generation feedstocks poses a risk to food security due to the increase in global population and decrease in available arable land resulting from rapid urbanization [4], [5], [6].

Hence, first-generation bioethanol production is criticized for competing with food and feed crops for resources. However, lignocellulosic biomass from agricultural and forestry residues, dedicated energy crops, and municipal and industrial wastes (second-generation feedstocks) are available, amounting to millions of tons and are not used as human food. Instead of being left to decompose and release greenhouse gases, these waste products can be utilized to produce bioethanol, thus promoting a circular and sustainable economy. At present, there are no cost-effective and environmentally sustainable technologies available for converting these residues into valuable products [7].

In addition, combining different types of organic wastes for co-fermentation has been suggested as a way to boost both the yield and quality of bioethanol. This approach can increase microbial diversity during fermentation, which in turn improves efficiency and enhances bioethanol output. Similarly, incorporating nanoparticles as additives has also been explored for their potential to support this process [8], [9]. The high surface-to-volume ratio of nanoparticles and unique properties like crystallinity, adsorption, and catalytic activity, make nanoparticles suitable for bioethanol production [10]. Bidir et al. [11] discussed the potential of nanomaterials for environmentally friendly bioenergy production and explained how nanomaterials could be used to increase the effectiveness of bioenergy storage and conversion in biofuels like bioethanol and biodiesel. Results of several studies reported in the literature have revealed the potentials of application of nanoparticles in enhancing the fermentation orco-fermentation process of waste products from rice, bananaor other biomass waste products. For example, Gupta and Chundawat[12] in their study on enhancing bioethanol production from rice straw, used biologically synthesized ZnO nanoparticles as a catalyst biological synthesized with fusariumoxysporum. In the study, ethanol yield was enhanced by using zinc oxide nanoparticles in a certain concentration range during fermentation. A maximum ethanol yield of 0.0359 g/g of dry weight-based plant biomass was obtained at 200 mg/L concentration of ZnO nanoparticles. Another study conducted by Nduka et al. [13] investigated the effect of nickel oxide nanoparticles (NiO NPs) on bioethanol production in the presence of yeast strain (Pichia kudriavzveii IFM 53048) from banana wastes. The study employed the hot percolation method for the green synthesis of NiO NPs and 99.95% of the substrate was utilized to give 0.23 $g/L/h^{-1}$ bioethanol productivity, and 51.28% fermentation efficiency, respectively. At 0.01 wt% of NiO NPs, maximum production was achieved with 0.27 g/g bioethanol yield. Furthermore, Sanusi et al.[14] investigated the impact of nanoparticle inclusion on the bioethanol production process using fresh potato peels. The study reported that the inclusion of NiO NPs at the pre-treatment stage gave a 1.60-fold increase and 2.10-fold reduction in bioethanol and acetic acid concentration respectively.Therefore, the use of nanoparticles in bioethanol production has notably improved the fermentation process for converting carbohydrate-rich biomass into biofuels by reducing common process challenges and associated costs. This is achieved by enhancing the reaction efficiency and selectivity involved in the conversion. As a result, the use of nanoparticles has emerged as a leading trend in current bioethanol production strategies.

However, to this extent, no study has investigated the integration of iron(iii) oxide and nickel oxide nanoparticles in the production of bioethanol from blends of organic wastes. Thus, in this study, Fe_2O_3, NiO NPs and their novel blend were synthesized and characterized. The synthesized nanoparticles were employed in production of enhanced bioethanol, and the effects of the synthesized nanoparticles on the yield and quality of bioethanol produced from various blends of banana peels and rice husks substrates were also investigated. Results of this study would not only provide valuable information for developing an effective strategy for production of enhanced bioethanol but will also serve as an efficient method for resources recycling and wastes management as well as for enhancement of the sustainability and economic viability of bioethanol production from various blends of banana peels and rice husks.

II. MATERIALS AND METHODS

2.1Collection of rice husks and banana peels and samples preparation

Rice husks used in this research studywere obtained from the Coscharis rice mill in Igbariam, Anambra State, Nigeria, while the banana peels were collected among the fruit sellers within the area. After hand-picking the lignocellulosic materials to clean the samples, they were ground into powdered forms using a milling machine. The homogenized small-size particles (25 nm) of the samples were obtained through sieving after grinding. Figure 1 presents the images of the fresh, sun-dried and powdered banana peels, while Figure 2 shows the images of the sun-dried and powdered rice husks.

(a) (b)

Fig. 1: Images of the: (a) fresh and sun-dried banana peels (b) powdered banana peels

(a) (b)

Fig. 2: Images of the: (a) sun-dried rice husks (b) powdered rice husks

2.2Characterization of prepared biomass feedstock samples

In this study, rice husks (RH) and banana peels (BP) were collected and prepared as described above for characterization using proximate, ultimate and composition analysis techniques.Thermo-gravimetric and elemental analysis can be subjected to any biological material to know the proximate analysis and ultimate analysis parameters. Regarding this study, those analyses were carried out on the two lignocellulose materials: rice husks and banana peels. The characterization techniques are used in determining the ultimate analysis parameters like carbon (C), nitrogen (N), and sulfur (S), the proximate analysis parameters such as moisture content, fixed carbon, ash, and volatile matter as well as the compositional analysis parameters.

2.3Synthesis of nanoparticles

Materials and chemicals used for synthesis of the nanoparticles were obtained from Joechem Ventures, Nsukka, Enugu State, Nigeria, and National Centre for Energy Research Development (NCERD), University of Nigeria, Nsukka (UNN).

For the synthesis of Iron (iii) Oxide, pure hematite nanoparticles were synthesized with the chemical precipitation method. In this procedure, an aqueous solution was prepared by dissolving an amount of iron(III) chloride hexahydrate ($FeCl_3$, $6H_2O$) in 100 mL of deoxygenated distilled water under magnetic stirring for 30min at 80^oC to obtain a 0.05M concentration solution (the same principle to obtain solutions of different concentrations (0.1, 0.2 and 0.4 M)). 50 mL aqueous solution of 2M of NH_4OH was used as the precipitating agent. Base solution (NH_4OH) was added gradually dropwise to maintain a pH value of 11. The reaction vessel was heated up to the temperature of 80ºC under magnetic stirring for 3 hours. The resulting precipitations were collected and centrifuged at 6000 rpm and then washed with distilled water and ethanol several times and finally dried in air at 80°C and calcined at 700°C for 4 h [15].

For the synthesis of Nickel Oxide nanoparticles,$NiCl_2.6H_2O$ and NaOH as starting material and double-distilled water as dispersing solvents were used to prepare NiO nanoparticles. At first, 5.94 grams of $NiCl_2.6H_2O$ was dissolved in 250 cm^3 double-distilled water as a solvent to get a certain molar concentration at room temperature. Then, the obtained solution was magnetically stirred for 40 min at a 50°C temperature. Afterward, the 10 cc NaOH with a certain molar was added drop-wise to the solution until the pH became 8. NiONPs were fabricated by chemical reaction as follows:

$$NiCl_2\,.6H_2O\,+\,H_2O\,+\,2NaOH\,\rightarrow NiO+\,8H_2O\,+2NaCl$$

In the final step, the obtained green gel was washed with distilled water and ethanol to remove the by-products formed during the reaction process and dried at 60^oC temperature for 14hrs. The dried samples were then calcined (annealed) at 500°C temperatures for 2hr to obtain NiO nanoparticles. Because of this annealation, the colour of the sample changes from green to black [16].

2.4Pretreatment process

Acid pretreatment method was carried out on the mixtures of the two lignocellulose materials (rice husks and banana peels). The feedstock blending mixtures were measured into different conical flasks with a chemical concentration of 0.2ml of sulfuric acid (H_2SO_4) and 40ml of distilled water (H_2O) solutions prepared and added into it, and then heated at 120^oC for 30 mins.

2.5Simultaneous saccharification and fermentation

The simultaneous saccharification and fermentation(i.e., hydrolysis) were carried out as described by Rawinder and Himanshu, (2017). Preparation of Basal Media: 1.2 g NaNO3, 1.4 g (NH4) SO4, 3.0 g KH2PO4, 6.0 g K2HPO4, 0.2 g MgSO4.H2O, 0.05 g CaCl2, 0.01 g MnSO4.7H2O, 0.001 g ZnSO4.7H2O, 1.4 g Urea, 1% Yeast extract, 2% peptone was added in 500 ml of distilled water and the volume was filled up to 1000 ml. The pH of the media was adjusted to 5.5-6.0 then heated at 121 ˚C for 15 minutes. Thus, 5% dextrose was added after heating the media. 100 ml of the enzymatic media was poured into each of the 250 ml flasks containing pretreated sample mixtures. After 72 hours, 2.5ml of S. cerevisiae was inoculated in the same flasks for the process of fermentation. 0.4g of Fe_2O_3, NiO and Fe_2O_3 + NiO (ratio of 1:1) nanoparticles were added in the bottles. The samples were then allowed to incubate for the next 72 hours at 28°C.The fermented samples were filtered by using filter paper to separate the solid substrate from the liquid and then distilled at 78˚C to get the bioethanol.The distillates collected were measured using a measuring cylinder and expressed as the quantity of bioethanol produced in g/l by multiplying the volume of the distillates collected by the density of bioethanol (0.8033). Figure 3 presents the experimental setup for the filtration process while Figure 4 showssome samples of bioethanol produced from the different blends of rice husks and banana peels (i.e., (100 wt.%RH:0 wt. %BP, 70wt.% RH:30 wt. %BP, 50wt. %RH:50 wt. %BP, 30wt.%RH:70 wt. %BP and 0wt.%RH:100 wt. %BP).

(a)

Fig. 3: Shows theexperimental setup for the filtration process.

(a) **(b)**

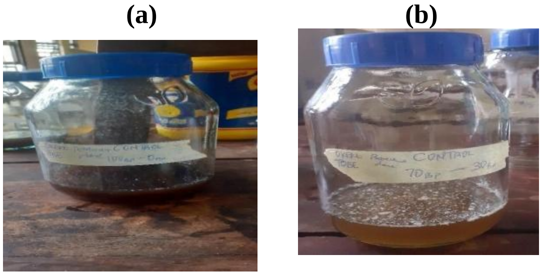

Fig. 4: Samples of bioethanol produced from different blends of rice husk and banana peels.

2.6Product analysis

Samples of bioethanol produced were characterized to determine the basic properties such as density, flash point, viscosity, specific gravity, and refractive index according to the American Society for Testing and Material (ASTM) Standard.

III. RESULTS AND DISCUSSION

3.1Characterization results

The results of the proximate, ultimate, and composition analysis of the biomass samples are shown in Tables1, 2 and 3, respectively. The moisture content of banana peel (56.02%) was much higher than that of rice husk (15.64%) and this might be due to the fact thatbanana peels contain more inherent moisture due to their biological structure and function.However, rice husk had the highest amount of volatile matter, ash content, crude fiber and crude fat of 20.45%, 65.54%, 37.87% and 2.70%, respectively as compared to banana peels. The ultimate analyses revealed that both banana peels and rice husk had almost the same nitrogen content with a slight difference of 0.04%. Banana peels had the higher carbon content of 62.64% as compared to that of rice husk which had 41.68%. Banana peels contain significant amounts of cellulose, hemicellulose, and lignin, which are organic polymers rich in carbon. These components contribute to the carbon content of the peels. On the other hand, rice husks also contain cellulose and hemicellulose but have a different ratio or concentration of these components compared to banana peels. The protein and lignin contents of rice husk are 3.37% and 25.83% respectively which are higher than those of banana peels (1.92 and 6.94 respectively). However, banana peels contained more carbohydrate content of 30.85% than rice husk having 20.56%.

Table 1:Proximate analysis results of biomass samples

	Moisture content (%)	Volatile matter (%)	Ash content (%)	Crude fiber (%)	Crude fat (%)
Rice Husk	15.64	20.45	65.54	37.87	2.70
Banana Peel	56.02	14.44	30.12	12.53	0.87

Table2:Ultimate analysis results of biomass samples

Parameters	Rice Husk	Banana Peel
Nitrogen content (%)	0.87	0.83
Carbon Content (%)	41.68	62.64

Table 3: Composition analysis results of biomass samples

Parameters	Rice Husk	Banana Peel
Carbohydrate(%)	20.56	30.85
Protein (%)	3.37	1.92
Lignin (%)	25.83	6.94

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3.2 Bioethanol yields

Figure 5 presents the bioethanol yields from feedstock samples of various blends treated with the nanoparticles (Fe_2O_3, NiO NPs and Fe_2O_3+NiO NPs (at 1:1 ratio)), and those of the untreated feedstock samples (i.e., the control samples) prepared using the same blending ratios. From the figure, it can be observed that the sample blend, 30 wt.% RH: 70 wt. %BP, treated with the blend of the nanoparticles (Fe_2O_3+NiO at the ratio of 1:1)produced the highest yield of bioethanol (27.8 g/l). This observation could be associated with the combined effect of the nanoparticles and probably coupled withthe co-fermentation effect of the blends of the two lignocellulosic biomass feedstocks with high contents of fermentable sugars, most especially, the banana peels (Table 3). Besides, it was also noticed that the least yield of bioethanol (23.2 g/l) was produced from the untreated sample blend,100wt.%RH:0wt.%BP, that contains only rice husks. On the contrary, the untreated sample blend, 0wt.%RH:100 wt.% BP, which contains banana peels alone gave a higher bioethanol yield of (25.6 g/l) when compared with the sample blend with only rice husks, probably due to the higher content of fermentable sugars and lower lignin level in banana peels than in rice husks (Table 3). This singular reason also appears to explain why the bioethanol yields from the feedstock samples treated with Fe_2O_3, NiO and Fe_2O_3+NiO NPs, in each of the samples blends, increased with the increasing weight percentages of the banana peels in the blends, respectively. It was also observed that the feedstock samples treated with Fe_2O_3 $_{NPs}$ gave higher yields of bioethanol than the samples treated with NiO NPs alone. This observation suggested that the Fe_2O_3 $_{NPs}$ is a better catalyst in the co-fermentation of rice husks and banana peels, enhancing the enzymatic activitiesthat facilitate the conversion of the fermentable sugars into bioethanol than the NiONPs.

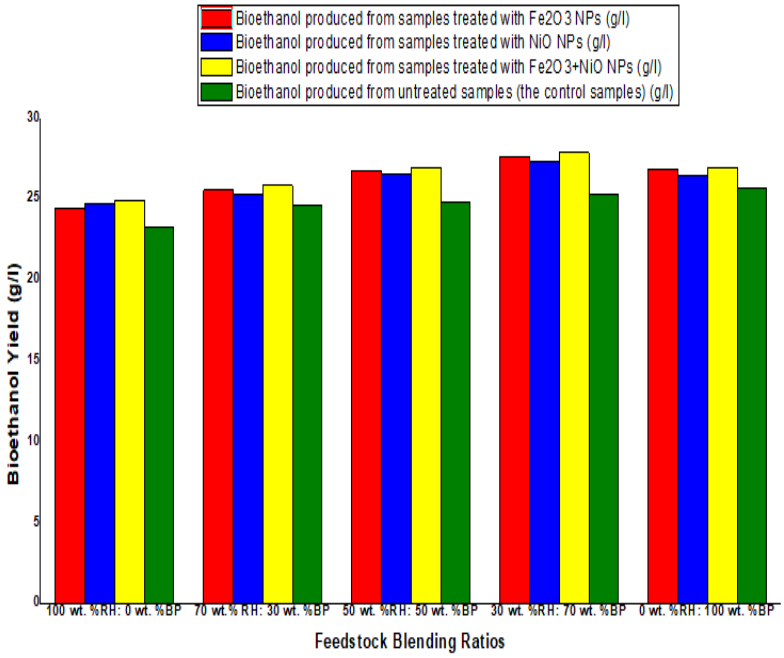

Fig 5: Bioethanol yields from feedstock samples of various blends treated with the nanoparticles and those of untreated feedstock samples (i.e., the control samples) at the same blending ratios.

3.3 Product analysis results

The analyses of the produced bioethanol samples showed how the addition of the nanoparticles influenced the quality of bioethanol obtained from the co-fermentation of rice husk and banana peels. The fuel properties of the produced bioethanol samples, such as density, flash point, viscosity, specific gravity, and refractive index, were assessed according to ASTM standards for petroleum products.

3.3.1 Density

The density of each produced bioethanol sample was measured by hydrometer method (ASTM D287 Standard) using a Digital Hydrometer (LCD English Display DH, BLS- 1298, USA).The densities of the bioethanol produced varied between 0.9986g/cm^3, which was produced by feedstock sample prepared from 100 wt.%RH:0wt.%BP sample blend but treated with Fe_2O_3 NP, and 0.764 g/cm^3, which was produced by the control sample prepared from 50 wt.%RH:50wt.%BP sample blend (Figure 6). These values are higher than the 0.74 g/cm^3 reported by Kheiralla et al. [18] and also the ASTM standard for density which is 0.789g/cm^3[19]. This shows that the bioethanolsamples produced contain more energy per unit volume compared to pure anhydrous ethanol, leading to better theoretical fuel efficiency and increased energy output [19]. It can be effectively blended with gasoline to produce fuel mixtures such as E10 (10% ethanol). However, bioethanol with a higher-than-standard density may not perform efficiently in engines calibrated for fuels that comply with ASTM specifications. This mismatch can result in engine knocking, reduced fuel economy, and potential engine damage. Fuel infrastructure—including storage tanks, pipelines, and dispensing systems—designed for ASTM-compliant ethanol may also face compatibility issues with high-density bioethanol, leading to increased wear and maintenance requirements. Moreover, a density exceeding ASTM standards may indicate the presence of impurities, such as water, which can be corrosive to certain materials and negatively impact combustion, engine performance, and emissions. To address these concerns, additional purification techniques like distillation or molecular sieving may be required to remove residual water. The slightly elevated density of bioethanol relative to ASTM D287 standards may also necessitate modifications to existing storage and transport systems, posing challenges in terms of infrastructure investment and operational adaptation.

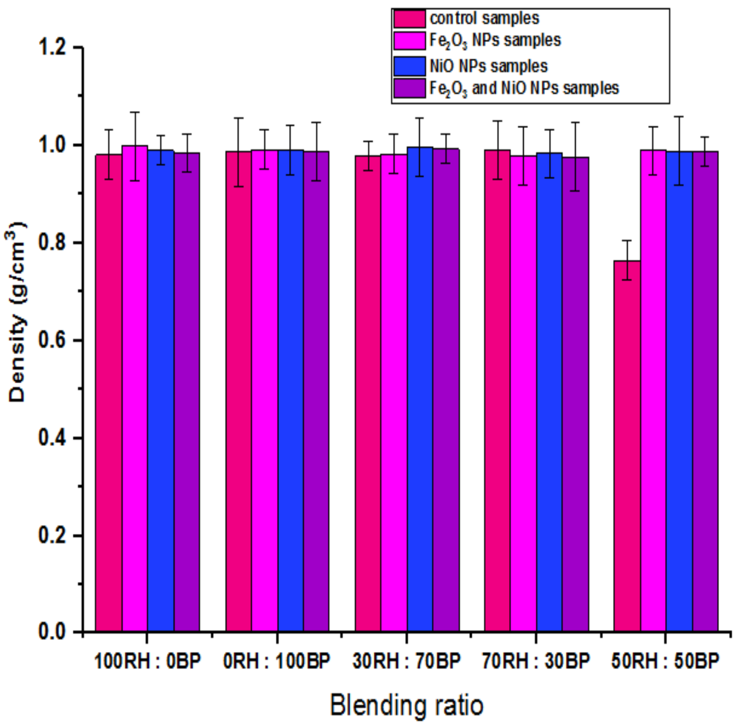

Fig 6: Densities of bioethanol produced under different treatments with nanoparticles

3.3.2 Flash point

The flash point of the produced bioethanol, which indicates its flammability and potential safety risks during storage and transportation, was determined using the Pensky-Martens apparatus [20]. From Figure 7, the analysis revealed that the flashpoints of the produced bioethanol fall within the range of 33°C to 40°C, which significantly exceeds the standard value of 17°C ASTM-D93 standard. It is important to note that the flashpoint does not impact engine performance, as highlighted by Lois et al. [21]. The bioethanol with a higher flash point indicates that it is less volatile and less likely to ignite compared to the ASTM-D93 standard of 17°C [22]. This could be seen as a safety advantage, especially in storage and transportation.However, this raises safety concerns related to engine performance. For efficient combustion, the fuel must ignite easily under operating conditions. Bioethanol with a high flash point may not ignite readily, resulting in incomplete combustion, reduced engine efficiency, and potential mechanical damage. Since engines are calibrated to operate with fuels possessing specific ignition properties, a significantly elevated flash point can cause problems such as misfiring, power loss, and decreased fuel economy.

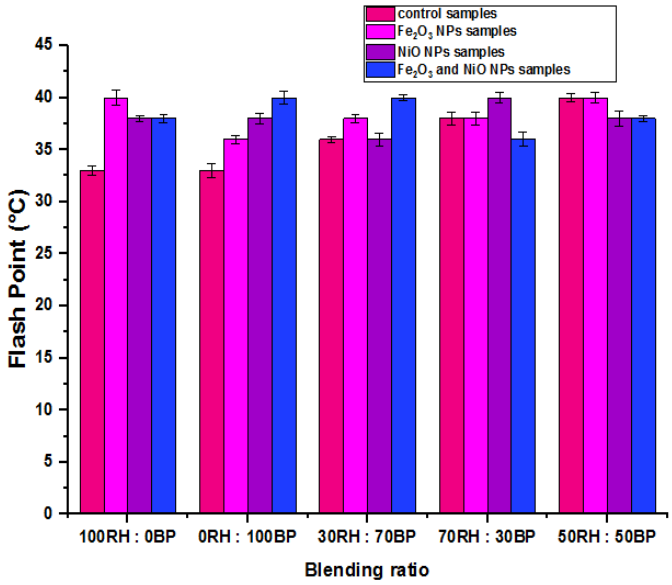

Fig 7: Flash points of bioethanol produced under different treatments with nanoparticles

3.3.3 Viscosity

The viscosity of the produced fuel is an important factor that impacts the efficiency of engine operation and combustion [23]. The viscosities of the produced bioethanol samples were measured using an Ubbelohde viscometer (Model 7143, India) in accordance with the ASTM D445–06 standard method. From Figure 8, the viscosities of the produced bioethanol fall within the range of 1.314 to 1.447 millipascal-seconds (mPas) at 20°C. This range is within the ASTM D445 set limit which falls within the range of 1.10 to 1.5 millipascal-seconds (mPas). The highest viscosity (1.447mPas) was recorded by the Fe_2O_3 NPs treated sample of 50wt.%RH + 50wt.%BP blending ratio, while the lowest viscosity (1.314 mPas) was recorded by the samples prepared with the feedstock blending ratios of 30wt.%RH + 70wt.%BP and 0wt.%RH + 100wt.%BP, but treated with NiO NPs and Fe_2O_3+NiONPs, respectively. From the results, it can be said that Fe_2O_3 NPs increased the viscosity of the bioethanol produced across all blends as compared to other additions of nanoparticles. These results agreed with other results in the literature that addition of nanoparticles increases the kinematic viscosity, flash point, fire point and other properties. [24], [25].

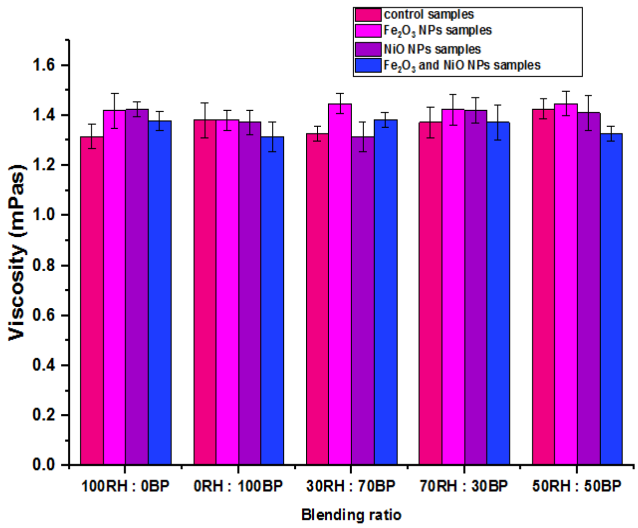

Fig 8: Viscosities of bioethanol produced under different treatments with nanoparticles

3.3.4 Specific gravity

Specific gravity is a fuel property that helps determine the appropriate mixing ratios, as fuels with different specific gravities can affect the general properties of the blend, such as octane rating and combustion characteristics [26]. The specific gravities of the bioethanol samples derived from various feedstock blends were measured using a digital density meter (DDM 2910, USA) following the ASTM D4052–16 standard method. The specific gravities of the produced bioethanol were within the range of 0.9496produced by the control sample of 30wt.%RH + 70wt.%BP to 0.9970produced by NiONPs treated sample of 30wt.%RH + 70wt.%BP blend which is higher than the ASTM standard value of 0.781 g/cm^3 (Figure 9). Deviations from the ASTM standard for specific gravity may affect the stability of ethanol-gasoline blends, such as E10 (10% ethanol) or E85 (85% ethanol), potentially requiring adjustments to the fuel formulations or engine properties.Also, when bioethanol has a higher specific gravity, it tends to deliver more energy per unit volume, which can improve fuel efficiency and output. This might also mean making changes to fuel systems, storage tanks, and transport setups to handle it properly.

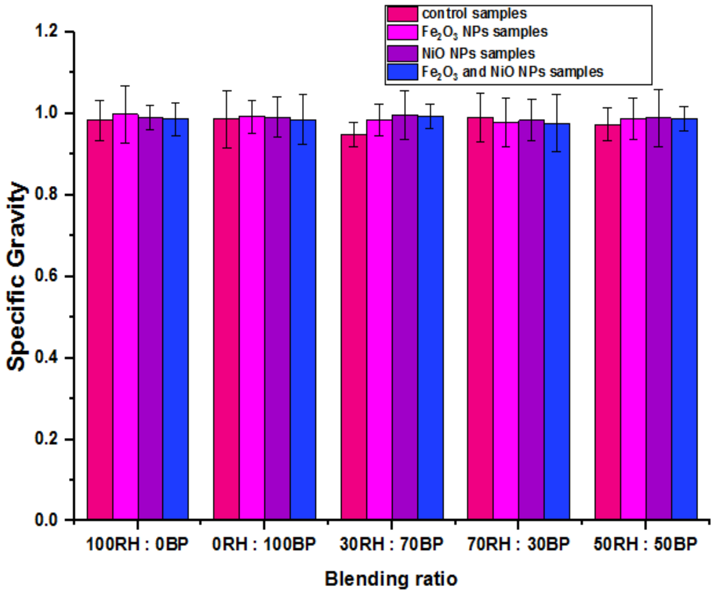

Fig 9: Specific gravities of bioethanol produced under different treatments withnanoparticles

3.3.5 Refractive index

The refractive indices of the produced bioethanol samples were measured using a digital handheld refract meter (DHR Misco PA202, USA) in accordance with the ASTM standard procedure. Figure 10 presents the resultsof the refractive indexes of the bioethanol produced under different nanoparticles treatments.From the figure, it can be observed that the highest value of the refractive index (1.3447) of bioethanol was produced from the sample blend 50wt.%RH + 50wt.%BPwith the addition of the blend of Fe_2O_3 and NiONPs. The lowest refractive index was 1.3433 from the control samples of 0wt.%RH + 100wt.%BP, 70wt.%RH + 30wt.%BP and the Fe_2O_3NPs treated sample of 50wt.%RH + 50wt.%BP blend, respectively. The refractive index of the bioethanol produced is slightly lower than the ASTM standardvalue of 1.362. This suggests that the composition of the bioethanol may be slightly different from the standard or that it could contain minor impurities. While the difference is relatively small, it could still indicate variations in the ethanol-water ratio or the presence of other compounds. Depending on the specific application, this slight difference in refractive index may or may not be significant. Some applications may have strict requirements for refractive index, while others may not be as sensitive to this parameter.

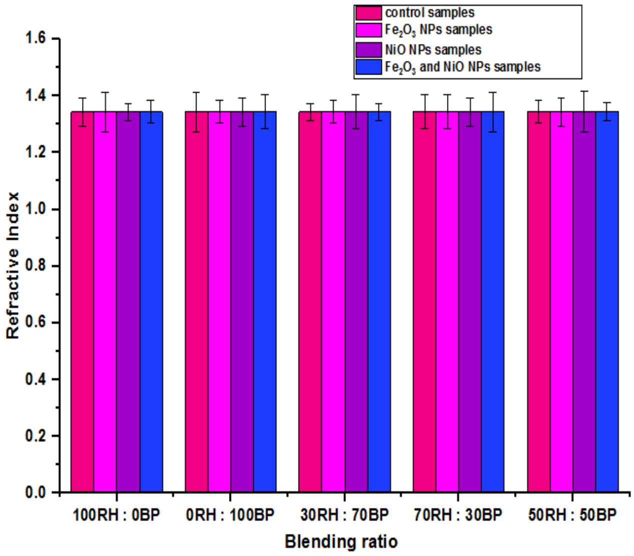

Fig 10: Refractive indexes of bioethanol produced under different nanoparticles treatments

IV. CONCLUSION

This study investigated the effect of iron (iii) oxide (Fe_2O_3), nickel oxide (NiO) nanoparticles (NPs) and their blend (Fe_2O_3+NiO at 1:1) on the yield and quality of bioethanol produced from fermentation of the blends of two different lignocellulosic materials: banana (Musa acuminata) peels and rice (Oryza sativa) husks. The rice husks (RH) and banana peels (BP) used in this study were collected, prepared and characterized using proximate, ultimate and composition analysis techniques. Acid pretreatment was employed to pretreat the prepared samplesbefore enzymatic hydrolysis, co-fermentation and product analyses were performed. Theresearch experiments were performed using different blending ratios of the rice husk and banana peels. The Fe_2O_3 NPs, NiO NPs, and their blend (Fe_2O_3+NiO at 1:1) were added accordingly to sample blends. Untreated feedstock samples without nanoparticles, but prepared using the same blending ratios, served as the control samples. Results revealed that the sample blend, 30wt. %RH: 70wt. %BP, treated with Fe_2O_3+NiO produced the highest yield of bioethanol (27.8 g/l). This could be associated with the combined effect of the nanoparticles and probably coupled with the co-fermentation effect of the blends of the two lignocellulosic biomass feedstocks. The least yield of bioethanol (23.2 g/l) was produced from the untreated sample blend, 100wt.%RH:0wt.%BP, that contains only rice husks. The untreated sample blend, 0wt.%RH:100wt.%BP, containing banana peels alone gave a higher bioethanol yield (25.6 g/l) than sample blend with only rice husks, probably due to higher content of fermentable sugars and lower lignin level in banana peels than in rice husks. Bioethanol yields from feedstock samples treated with Fe_2O_3, NiO and Fe_2O_3+NiO NP respectively were observed to increase with the increasing weight percentages of banana peels in the blends. The feedstock samples treated with $Fe_2O_{3\ NPs}$ gave higher yields of bioethanol than samples treated with NiO NPs alone. This suggested that $Fe_2O_{3\ NPs}$ is a better catalyst than NiO NPs.in this specific reaction, enhancing enzymatic activities that facilitate conversion of sugars into bioethanol.

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