Development of a Sustainable Nano-refrigerant using agro-waste (rice husk ash) as a base material for a domestic refrigeration system

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Abstract. Silica nanoparticles were synthesized from Rice husk ash (RHA) through the top-down approach production greyish coloured particles. The spectroscopical investigation showed a compositional analysis of 74.6% silicon, 20% oxygen and 5.4% carbon. Microstructural studies indicated an average particle area of 7.8nm^2 and average particle size of 4nm. The nanoparticles were dispersed into the lubricant oil of the compressor such that when the refrigerant is dispersed over the compressor, the particles mix with the refrigerant giving the nano-refrigerant mixture. The nanoparticles were dispersed into the mineral oil at concentrations of 0.2wt%, 0.3 wt%, 0.5 wt% and 0.6 wt% and fed into the compressor to combine with the refrigerant in the vapour compression system. The refrigerator was run for 240 minutes for each sample as well as the control sample which was the refrigerant R600a. Performance evaluation was carried out to assess the viability of the developed nano-refrigerant. Generally, an increase in the refrigerating effect compared to the control sample by all concentrations apart from the 0.6wt% by 13, 7.5, and 12.5% and a corresponding increase in the COP by 31, 23 and 35% compared to the control sample for the 0.2 wt%, 0.3 wt% and 0.5 wt% concentrations respectively was recorded.

1 Introduction

The term refrigeration simply refers to the process of removing heat or chilling an area below its ambient temperature [1]. Refrigeration began with the usage of ice to preserve food in pre-historic times. Ancient cultures such as the Chinese, Hebrew, Greeks, Persians

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and Roman all practiced this. In caves lined with straw and other insulating materials, the ice was maintained and preserved [2].

The four major components of a basic refrigeration system are arranged in sequence with their operations. The compressor raises the pressure and temperature of the refrigerant, and supplies it to the condenser. Heat is released from the refrigerant in the condenser then delivers it into the expansion valve. An expansion valve converts the pressure in the condenser to the pressure in the evaporator. The refrigerant is then injected into the evaporator. The Evaporator absorbs the heat from the space to be cooled and delivers it to the compressor via the refrigerant. Therefore, the cycle continues [3].

Nanotechnology is a field concerned with the development of nano-sized particles ranging in size from 1 to 100nm through advanced synthesis and particle size modification techniques. The use of nanotechnology has produced positive outcomes in fields such as physics, biology, organic and inorganic chemistry, and medicine [4]. Nanofluid is the infusion of nanoparticles in base fluids that have been tailored to improve their properties at low concentrations. It's high surface area increases the heat transfer surface between particles and fluids [5]. Nano refrigerant is a type of nanofluid generated from the proper infusion of nanoparticles in the base refrigerant combination. Its improved thermal properties in relation to the base refrigerant-oil combination improves the heat transfer characteristics. As a result, using nano refrigerant results in a lighter system, thereby improving the heat transfer characteristics of the refrigeration system [6].

In terms of increased heat transfer qualities, wear efficiency, and excellent refrigerant-lubricant solubility properties, nano-refrigerants and nano-lubricants are good choices for boosting the effectiveness of the vapor compression system [7].

Agricultural waste management as gained a lot of attention recently. The idea of repurposing industrial and agricultural waste materials in replacing scarce resources and developing different approaches to conserve natural resources. As public knowledge of the negative effects of certain processes has significantly grown, as such, using agricultural and industrial waste by-products as an alternative for waste disposal has become an increasingly appealing option [8]. The use of nano refrigerants have been investigated by researchers in the past. Basically, researchers have studied different ways to improve the efficiency of a refrigeration system [9]. One popular method that has been attempted involved the use of nanoparticles in varying combinations. In this method, focus is placed on characteristics such as flow boiling, pool boiling, tribological and condensation properties in nano-refrigerants, as well as energy savings gains using a nano-lubricant. Researchers have found that this method resulted in an improved heat transfer rates and coefficients of performance [9]. Invariably, thermal conductivity is a key parameter that guides the choice of a working fluid in a refrigeration system. Hence, the use of nanoparticles in place of conventional refrigerants could result in increased thermal conductivity as temperature increases. This increment eventually results in an improved coefficient of performance [10-12].

When titanium dioxide (TiO_2) as well as aluminum oxide (Al_2O_3) nanoparticles are dispersed in ethylene glycol as well as deionized water in 50:50 volumetric proportions, at a temperature of 25 °C, the density and viscosity of the aluminum oxide nanofluids increased by 2.32 percent and 11.71 percent, respectively. Basically, the introduction of nanoparticles was responsible for the improvement recorded for both the density and viscosity. This proves that the use of nanoparticles had the capacity to accelerate performance of some media/working fluid when introduced in specified mass fractions [12-13]. The excellent performance of these nanoparticles remain arguable since in some studies it was found that its introduction to the base media didn't make much difference in overall system performance [14-15]. However, due to the excellent performance recorded in most cases, it is safe to further experiment on this theory. Hence, in this study, a nano-refrigerant was developed for a domestic refrigeration system using rice husk ash as base material.

2 Materials and Methods

2.1 Materials and Equipment

The materials used in the preparation of the silica nanoparticles for this study were Rice husk ash, Sodium hydroxide (NaOH) [3 molarity], Sulphuric acid (H_2S0_4), Distilled water, Refrigerant, Litmus paper. The following equipment were adopted in the production and characterization processes such as a digital electronic weighing balance, scanning electron microscope (SEM) for microstructural examination, pipette, a Sonicator, magnetic stirrer, centrifuge, muffle furnace, beakers, decanted keg, test tubes, oven, an ultrasonic bath, spatula, domestic and refrigerator.

2.2 Experimental process

2.2.1 Production of RHA

The Rice husk was gotten from a local market in Ogun state. The rice husk was initially washed with distilled water to rid it of its impurities then dried for an interval of 8 hours [1]. Thereafter the dried rice husk was then turned into ashes with the help of a furnace at 500°C for 8 hours.
The product obtained was black ash and was cooled for about 12 hours. Thereafter, the rice husk was grounded into powder form then milled. The ash received was sieved to obtain ash of fine consistency and reduced impurities which were used as the base for the silica nanoparticle synthesis, *Figure 1*.

Fig. 1. Burnt rice husk ash.

2.2.2 Development of silica oxide nanoparticle from RHA

Previously used methods of synthesizing nanoparticles have proven dangerous to the Eco-system therefore an environmentally friendly alternative for the synthesis of nanoparticles was used [1, 4-6]. The development silica nanoparticles from RHA was achieved by chemical means. This method involved the use of sodium hydroxide (NaOH) as a precursor salt to dissolve the silica to form sodium silicate. The sodium silicate solution was then neutralized with H2SO4 drop wise to precipitate the silica to form silica gel. This was then dried for about 48 hours in the oven and thereafter calcinated in the furnace to form the silica nanoparticles powder. A detailed overview of the step-by-step process of the preparation is highlighted below.

(a) Reaction process

30g of Rice husk was placed on the platform of the digital electronic weighing balance for accurate measurement. The weighted sample was then mixed with 120g of sodium hydroxide (NaOH) pellets and 1500ml of distilled water in a beaker to form an aqueous solution. The solution was then stirred in a beaker for about 4 hours on a Stuart US 152 heat-stir magnetic stirrer/ hot plate at 100 °C to form a darkened solution of sodium silicate, *Figures 2a & 2b*.

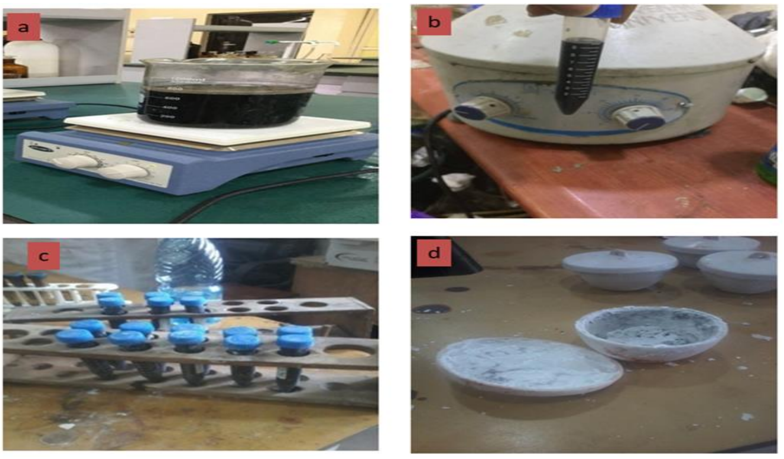

Fig. 2. (a) Stuart magnetic stirrer (b) Centrifuge (c) centrifuged fluid in the test tube (d) Nanoparticles after calcinations

After mixing, the solution was allowed to cool to an ambient temperature until neutralization was carried out. The sodium silicate solution was then given 1000 ml of 10% H2SO4 in dropwise additions while being vigorously agitated until the pH of the solution was brought down to 7 to create silica gel. For around 48 hours, it was allowed to age in order to precipitate more.

The reaction equations for chemical synthesis:

SiO_2 (RHA) + 2NaOH = $Na_2SiO_3 + H_2O$

$Na_2SiO_3 + H_2SO_4 = SiO_2 + Na_2SO_4 + H_2O$

(b) Centrifugation process

The solution obtained at the end of the previous process was poured into 10ml centrifuge tubes and left to cool and settle. These tubes were then placed in a JZ centrifuge Model 0406-2 to be spun at 4000 rpm for 15 minutes to separate the nanoparticles. The centrifuge was used to create the nanoparticles from the fluid by applying centrifugal forces in order to separate larger particles from the watery solution, as shown in Figure 2c. The fluid in the tube floats above the particles, forcing them to accumulate at the bottom. As a result, the nanofluids float on top of the nanoparticles, which are deposited at the tubes' bottoms. The particles remained in the tube while the liquids were decanted and kept in a bottle. Until all of the solution had been centrifuged and decanted, the procedure was repeated.

(c) Carbonization Procedure

Following centrifugation, the nanoparticles were transferred from the centrifuge tubes into the crucible and calcined for 6 hours in the muffle furnace, where they were subjected to extremely high temperatures [8-9]. This resulted in clusters of a powdered, black material. Before putting the powder into sample containers for characterisation and testing, the clumps were removed using a small mortar and pestle, as shown in Figure 2d.

2.3 Materials properties of rice-husk ash (RHA) and silica nanoparticles

The surface topography and structural analysis of the nanoparticles and Rice husk ash were determined using a Scanning Electron Microscope as well as an FT-IR to investigate the surface absorption of functional groups on nanoparticles. The secondary electron (SE), back-scattered electrons (BSE), characteristic X-rays, light (cathodoluminescence) (CL), specimen current and transmitted electrons are the types of signals produced by a SEM include while the secondary electron imaging can produce very high-resolution images of a sample surface of less than 1 nm sizes. In preparation, the samples of the needed size was inserted into the specimen chamber and coated with platinum coating of electrically conducting material while being placed rigidly on a specimen holder.

2.4 Preparation of silica nano-fluid

The nanoparticles were weighed using an electronic balance to give five different varying mass concentrations from 0g-2g (0.2 wt.%, 0.3 wt.%, 0.4 wt.%, 0.5wt.%, 0.6 wt.%) of the silica nanoparticles. Each of the weighted nanoparticle samples were dissolved in 250ml of mineral oil then were sonicated for 3 hours per sample in an ultrasonic bath to improve the homogeneity of fluid and an evenly dispersion in the base fluid and greater stability, Figure 3.

Fig. 3. Nanofluid after sonication

2.5 Experimental application of nano-refrigerant in home-refrigerator

The production of nano-refrigerant was conducted experimentally in a residential refrigerator installation with extra equipment like pressure gauges, thermocouples, and watt meters. The suction and discharge pressures were measured using pressure gauges, and the temperatures at the inlet and outlet of the evaporator and condenser were measured using thermocouples. Various volumes of the nano-fluid specimen were added to the 40g of R600a refrigerant that was used to charge the refrigerator each time. For every specimen, the experiment was ran for 240 minutes, and variables like suction temperature and pressure, discharge temperature and pressure, and cabinet temperature were recorded. The pull down time, refrigerating effect, coefficient of performance, specific heat capacity, and thermal conductivity were then computed using these data and compared to readings from a control sample.

3 Results and Discussions

3.1 Evaluation of Microstructural Analysis

The Agro-waste RHA and nanoparticles produced were analyzed using Scanning Electron Microscope (SEM). The rice husk ash was obtained after the rice husk was washed and sun dried at intervals of 8 hours then burnt into ashes using a furnace at 500 °C for 8 hours. The micro-graph taken at magnification of 18000 and working distance of 18mm indicates many residual pores distributed in the sample. This shows the high porosity of the silica and its large internal surface area and overall particle size, Figure 4a. The silica has a grey color as a result of it being burnt. The analyses were taken at magnifications of 7000, 8000 and 9000 with a working distance of 10.4mm for each and an accelerated voltage of 20V. The results showed near spherical particles in clusters which tally with previous research, Figures 4b - 4d.

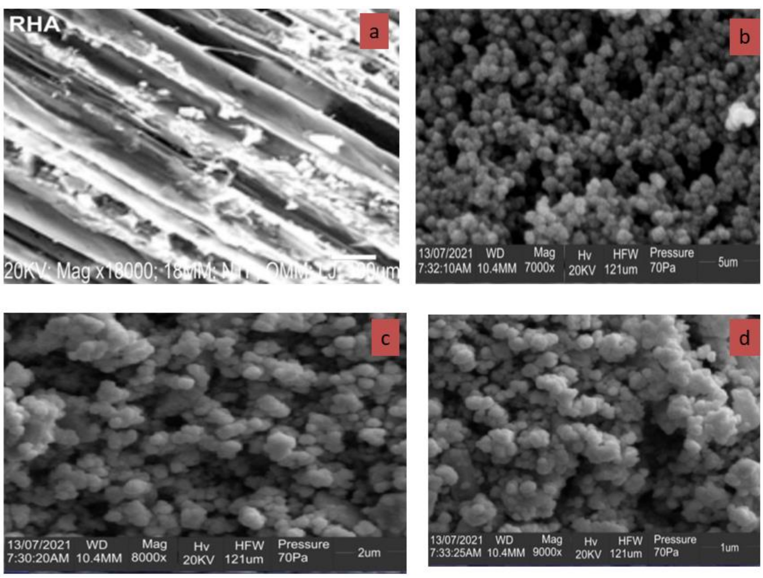

Fig. 4. (a) SEM Micrograph of Rice Husk Ash; (b)-(d): SEM Micrographs of developed nanoparticle powder at MAG 7000, 8000 and 9000 respectively

3.2 Net Refrigerating Effect

The net refrigerating effect is the difference between the enthalpy of the refrigerant leaving the evaporator in its vapor phase and the enthalpy of the liquid just upstream of the expansion valve entering the evaporator. It can also be defined as the amount of heat that each mass of the refrigerant retains from the refrigerated space. Figure 5 shows the net refrigerating effect for each concentration.

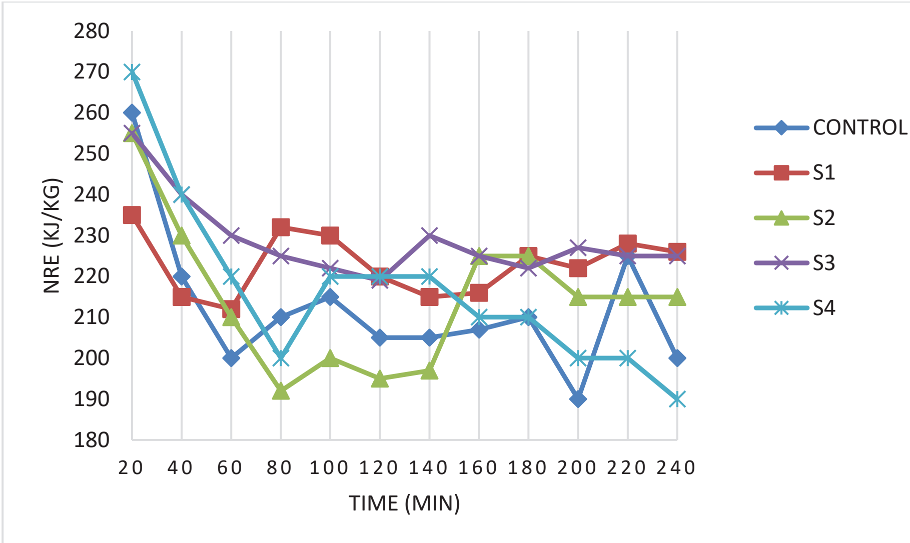

Fig. 5. Graph of variation of net refrigerating effect

Basically there is an initial drop of the refrigerating effect at the start of the experiment followed by a steady rise and stabilization through to the end of the 4 hours. The higher the net refrigerating effect, the higher the quantity of heat retained from the space at an interval of time, therefore the lower the power consumption. The 0.2 wt% (S1), 0.3 wt% (S2) and 0.5 wt% (S3) concentrations showed the highest net refrigerating effect with 13, 7.5, and 12.5% greater NREs than the control respectively. The 0.6 wt% (S4) had the lowest NRE, which was 5% lower than that of the control, Figure 5.

3.3 Power consumption

This is the power consumed through the experiment for each sample concentration. The values were gotten using a watt-meter and plotted against time for each concentration. Figure 6 shows the values as the system was monitored.

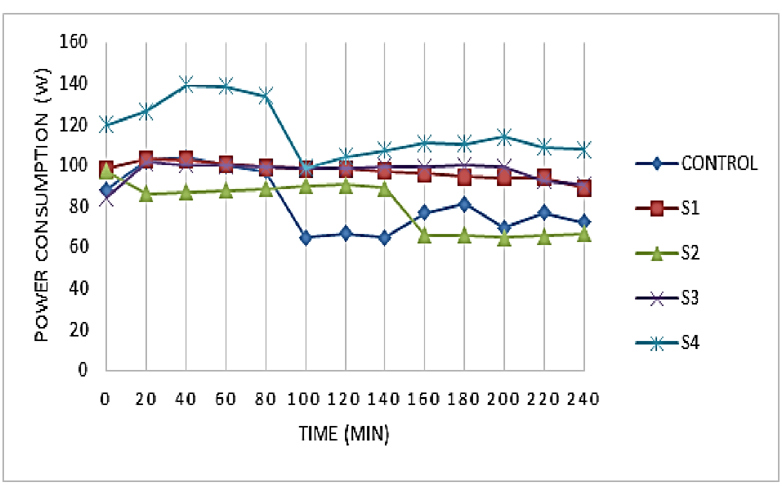

Fig. 6. Graph of variation in power consumption

4 Conclusion

This study involved the development of Silica Nano-particles from rice husk ash and its use as a nano-refrigerant. The microstructures of the rice husk ash and the developed silica nanoparticles have been examined and discussed. The net refrigeration effect and power consumption have also been discussed. The results from the study are as summarized below:

- The SiO_2 nanoparticles were successfully synthesized from the prepared agro-waste (Rice husk ash) using the top-down chemical method. The particles gotten had a greyish appearance similar that of previous research.
- Characterization of the nanoparticles using the field emission scanning microscope and the spectrometer showed near spherical nanoparticles with an average particle area of 7.8nm^2 and the maximum and minimum area values ranging from 16.79 to 1.94nm^2. The analysis also showed a mean nanoparticle length of 4nm confirming its nanoparticle size.
- The results also showed a reduction in power consumption for the sample 0.3 wt% by 9% compared to the control. The samples 0.5 wt% and 0.6 wt% showed the best pull down times with temperatures of -3.1°C and -6.1°C respectively.
- All samples also showed a greater refrigerating effect than the control sample apart from the 0.6wt% concentration. The results also showed an increase in the specific heat capacity across all samples as compared to the control by 0.6-5.3%.

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