Improving the Thermo-Physical Properties of Plam Oil with Zeolite Nanoparticles

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Abstract. This research aimed to improve the thermo-physical properties of plam oil with NaA zeolite. Palm oil was selected for heating oil due to its high flash point and environmental friendliness compared to synthetic or mineral oil. The effect of NaA zeolite concentration suspended in palm oil was investigated in terms of the specific heat capacity (Cp), viscosity (μ), viscosity index (VI), thermal analysis (TGA) and density (ρ) of palm oil. The NaA zeolite was synthesized by crystallization technique, and X-ray diffraction analysis was performed to determine NaA zeolite crystallinity. The size of NaA zeolite was measured using a particle size analyzer. The average size of the synthesized NaA zeolite was 4767 nm. After grinding process for 180 min, the average size of zeolite decreased to 632 nm. An average 632 nm NaA zeolite particle size was added to palm oil at 0.25, 0.5, 0.75 and 1 wt%. The results showed that when the NaA zeolite concentration increased, the nanofluid's viscosity at 40 °C and 100 °C was increased. The addition of 1 wt% NaA zeolite resulted in the nanofluid having a maximum viscosity of 41.31 and 8.47 cSt at 40 °C and 100 °C, respectively. The highest viscosity index was 195 cSt when added with 0.5 wt% NaA zeolite. The density of palm oil slightly increased with increasing NaA zeolite concentrations. The specific heat capacity of palm oil increased when NaA zeolite was added. The results showed that NaA zeolite allowed palm oil to store heat energy better than palm oil, enabling it to release and absorb more heat during heat transfer. Thermogravimetric analysis, palm oil initiated to degrade at 263 °C, while the addition NaA zeolite in palm oil indicated that palm oil initiated to degrade at 350 °C. The shift in the degradation curve demonstrated that the nanofluid could withstand high temperatures. Adding NaA zeolite to palm oil showed that palm oil could endure more heat and has a long service lift.

Introduction

Nowadays, thermal oils are widely used as industrial heat transfer fluids in many process applications such as heat exchangers, cooling system drilling, lubricating process, and solar application. The most commonly thermal fluids should be suitable for various temperatures. However, mineral or synthetic oils are petroleum-based and tend to cause resource depletion. The emergent concern to reduce the use of petroleum derivative mineral oil has led to the research for eco-friendly heat transfer fluid. The mineral oil-based heat transfer fluid has the low biodegradation rate and a high potential for bioaccumulation and toxicity [1]. Therefore, the synthesis of heat transfer fluid from vegetable oil is an alternative because there is a renewable source, environmentally friendly, less toxic, and economical in reducing waste treatment costs due to its inherently higher biodegradability and high flash point.

Ramasamy et al. [2] investigated palm kernel oil had heat transfer potential when compared with Therminol 66 was classified as synthesis oil. Palm kernel oil properties were closely matched with synthetic oil and offered the following properties: thermal conductivity 0.142 W/m·K, the dynamic viscosity of 5.2 mPa·s, specific heat 2.4 kJ/kg·K, and density 852 kg/m^3. Therefore, palm oil was an alternative to heat transfer fluid. The exciting issue of palm oil was thermal stability lower than heat transfer oil commercial grade.

Many research groups had worked on nanoparticle suspending in oil as a based fluid to enhance thermal stability. For example, Sunil et al. [3] attempted to improve the thermal stability of rice bran oil by dispersing CaO nanoparticles. The result showed that rice bran oil's thermal stability was considerably enhanced by 18.2% and 25% due to adding 0.25% and 0.50wt% of CaO-nanofluids, respectively. Furthermore, Ilyas et al. [4] investigated the dispersion of multi-wall carbon nanotubes in thermal oil. The result showed that nanofluids with high concentrations of nanotubes can operate at higher temperatures than pure thermal oil.

Palm oil was used as a based fluid due to the friendly environment, highly stable, and oleic acid group in palm oil coated on the surface of nanoparticles against aggregation of nanoparticles. In this study, the effect of the concentration of NaA zeolite suspended in palm oil on the specific heat capacity (Cp), viscosity (μ), viscosity index (VI), thermogravimetric analysis (TGA), and density (ρ) of palm oil was investigated.

Experimental

NaA zeolite was synthesized by hydrothermal crystallization process using sodium aluminate and sodium metasilicate pentahydrate as a precursor material. NaA zeolite was prepared by dissolving sodium hydroxide and sodium aluminate in deionized water. The sodium metasilicate solution was added to the above solution under stirring for 1 h. The solution was refluxed for 1 h at 110 °C. After crystallization, the solid products were filtered off, washed with DI water, and dried at 110 °C for 24 h. Powder X-ray diffraction (XRD) patterns were obtained using the X-ray powder diffractometer (Rigaku, USA) with Cu Ka radiation, operated at 30 mA and 40 kV. The milling process was performed using a planetary ball milling (MTI Corporation TMAX-XQM, USA), and grinding time varied from 30, 60 and 180 min with a constant rotational speed of 500 rpm. Particles sizes were determined with a particle analyzer (Beckman Coulter delsa Nano C, USA). The NaA zeolite with size 632 nm was dispersed into 100 g of palm oil at 0.5, 0.25, 0.75 and 1 wt% and stirred for 20 min. After that, the nanofluid was homogenized using an ultrasonic bath for 45 min.

The viscosity of the nanofluid was measured using a Cannon Instrument viscometer (USA). The density of nanofluid was measured using density meter (Anton Paar, Thailand). The specific heat capacity of the nanofluid was measured using a differential scanning calorimetry (TA Discovery DSC25, USA). The thermal behavior was observed through simultaneous thermogravimetric analyzer (Shimadzu DTG-60H, Japan) in air from room temperature to 600 °C at a fixed heating rate of 20 °C /min.

Results and Discussions

XRD pattern of the synthesized zeolites was shown in Fig.1. XRD observed the characteristic peaks closely matched with NaA zeolite structure [5]. The characteristic 2θ peaks at 16.2, 21.9, 24.1, 27.3, 30.1 and 34.3 corresponded to the (420), (600), (622), (642), (644) and (664) planes of typical LTA zeolite structure. Particle size measurements from the particle analyzer showed that the NaA zeolites had an average particle size of 4676 nm. The influence of milling time on the average particle size of NaA zeolite was shown in Table 1. The results showed that the average particle size of NaA zeolite decreased from 4676 nm to 978 nm after grinding for 30 min. The grinding period extension was increased to 60 and 180 min, resulting that the average particle size decreasing to 732 and 632 nm. Therefore, the smallest NaA zeolite, 632 nm, was selected to be dispersed into palm oil.

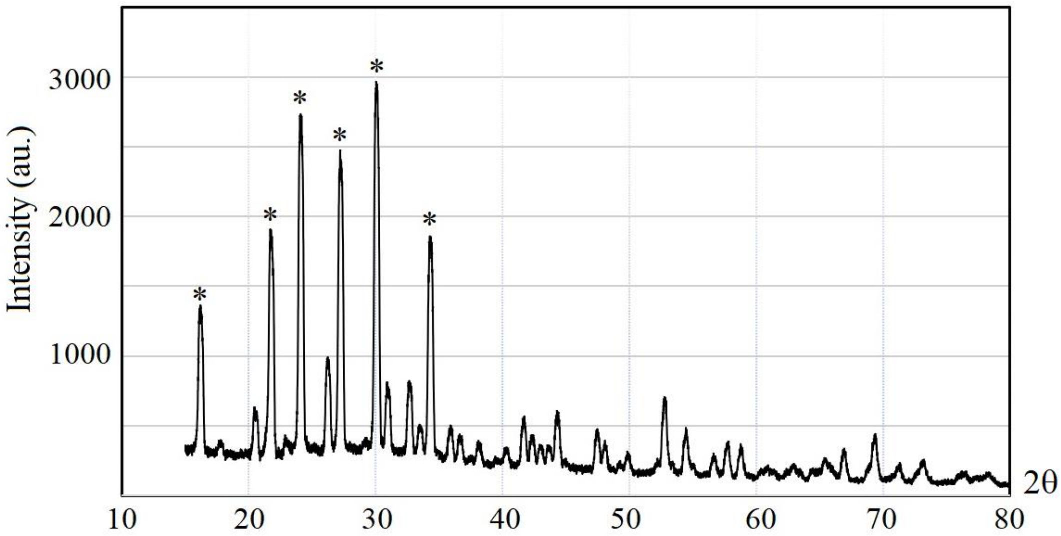

Fig. 1. XRD pattern of the synthesized NaA zeolite.

Table 1. The effect of milling time on size of NaA zeolite particle.

Milling time [min]	Average particle size [nm]
0	4676
30	978
60	732
180	632

The effect of the concentration of NaA zeolite, 632 nm, on the viscosity of palm oil at 40 °C and 100 °C was shown in Fig.2. The results showed that when the concentration of NaA zeolite increased, the viscosity of the nanofluid at 40 °C and 100 °C was increased. The addition of 1 wt% NaA zeolite resulted in the nanofluid having a maximum viscosity of 41.31 and 8.47 cSt at 40 °C and 100 °C, respectively. This increased viscosity was due to nanoparticles placed between oil layers. With increased concentration, nanoparticles become agglomerated, creating more oversized and asymmetric particles, collision will be increased. Therefore, the fluid layers could not move on each other compared to the base fluid, leading to increased viscosity [6].

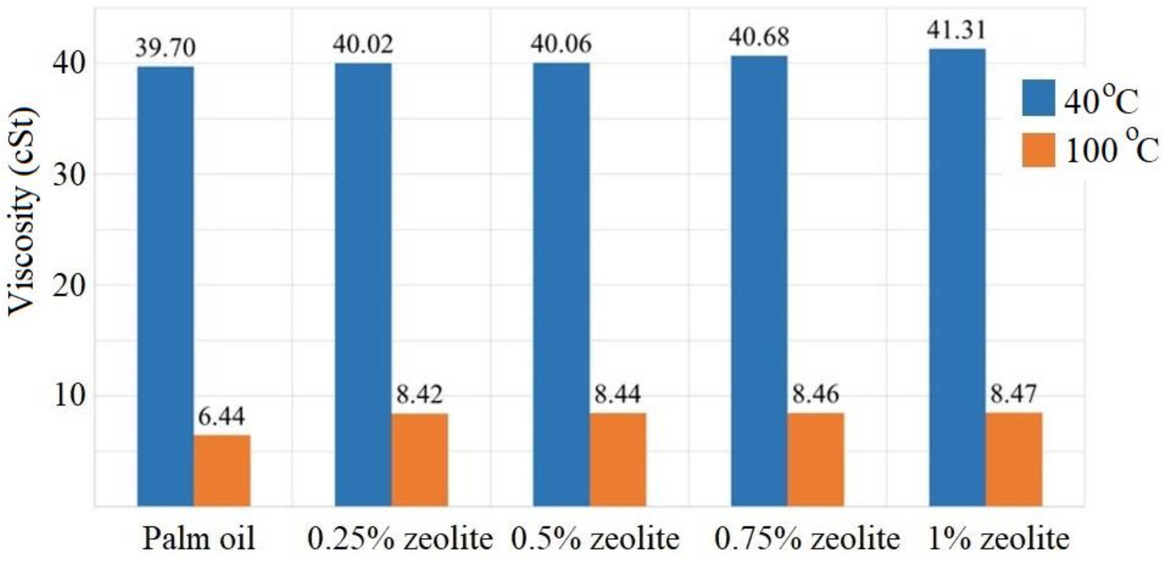

Fig.2. The effect of NaA zeolite concentration on the viscosity.

The effect of nanoparticle concentration on the viscosity index was shown in Fig. 3. The viscosity index of palm oil was 113 cSt and the viscosity index of the nanofluid with 0.25%, 0.5%, 0.75% and 1% wt. of NaA zeolite were 194, 195, 191, and 188 cSt, respectively. The viscosity index increased with the addition of nanoparticles because nanoparticles had a high surface area and formed a stable network or structure within fluid, leading to improved viscosity-temperature behavior. In addition, the network created by the nanoparticles maintains fluid viscosity at various temperatures, resulting in a higher viscosity index.

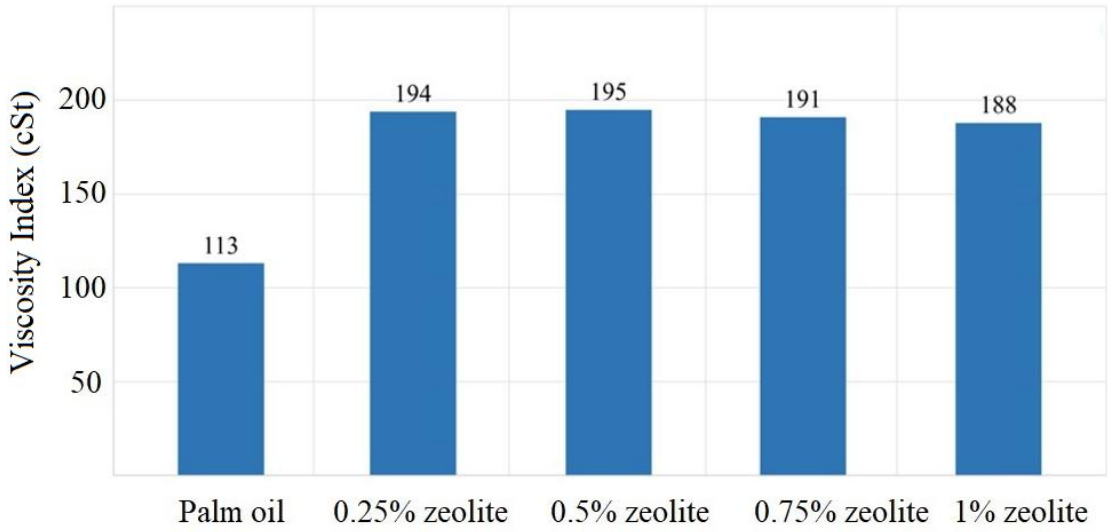

Fig.3. The effect of NaA zeolite concentration on the viscosity index.

The influence of nanoparticle concentration on palm oil density at 25 °C (ASTM D6304) was shown in Fig.4. It was found that the densities of nanofluid containing 0.25%, 0.5%, 0.75% and 1% nanoparticles slightly increased to 0.919, 0.920, 0.921, and 0.923 g/cm^3, respectively. Because particles were added to palm oil, the mass of the nanofluid increased, and the density of the nanofluid increased.

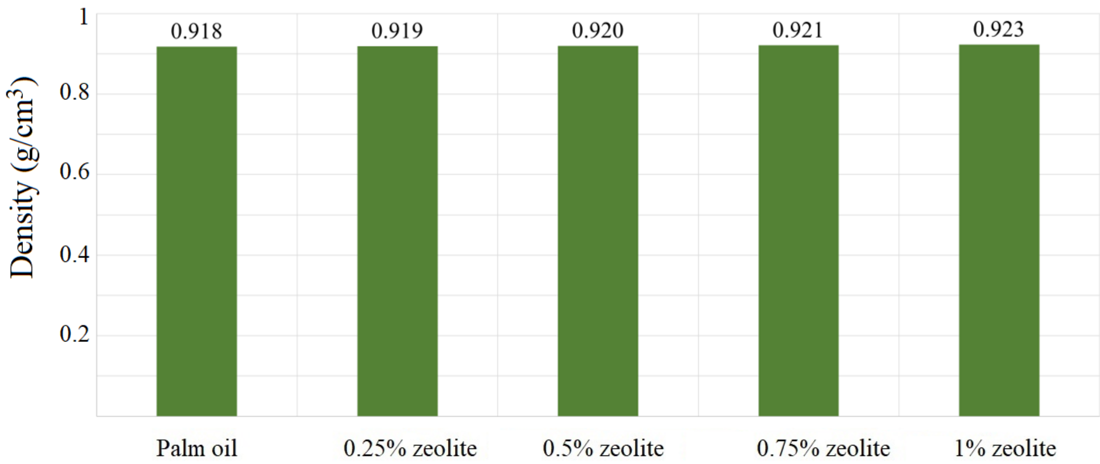

Fig.4. The effect of NaA zeolite concentration on the density.

The specific heat capacity of palm oil and nanofluid were shown in Table 2. The results showed that the specific heat capacity of palm oil containing 0, 0.5% and 1% NaA zeolite by weight was 1.807, 2.078 and 2.136 J/g·°C, respectively. The specific heat capacity of nanofluid was higher than that of palm oil due to the formation of a compressed layer at the interface between solid particles and liquid molecules [7]. That improved the thermal energy storage capacity of the nanofluids.

Table 2. Specific heat capacity of palm oil and nanofluid.

Sample	Specific heat capacity [J/g·°C]
Palm oil	1.807
0.5% zeolite	2.078
1% zeolite	2.136

Thermogravimetric analysis (TGA) in Fig.5 was performed to investigate the effect of nanoparticle concentration on the degradation of palm oil. The results in Fig. 5(a) showed that palm oil initiated to degrade at 263 °C, while the addition of 0.5 and 1wt% NaA zeolite in palm oil indicated that palm oil initiated to degrade at 350 °C. The shift in the degradation curve demonstrated that the nanofluid could withstand high temperatures. The derivative of thermogravimetric analysis (DTGA) was determined for all nanofluid samples to understand the degradation phenomenon and the significance of nanoparticle concentrations on the lifespan of palm oil. The peak positions were shown in Fig.5 (b), indicating that the maximum change in weight loss for palm oil occurred at 417 °C. With the addition of 1 wt% zeolite NaA particles, the peak was shifted to 434.6 °C. These results showed an increase in the degradation temperature due to the presence of nanoparticles.

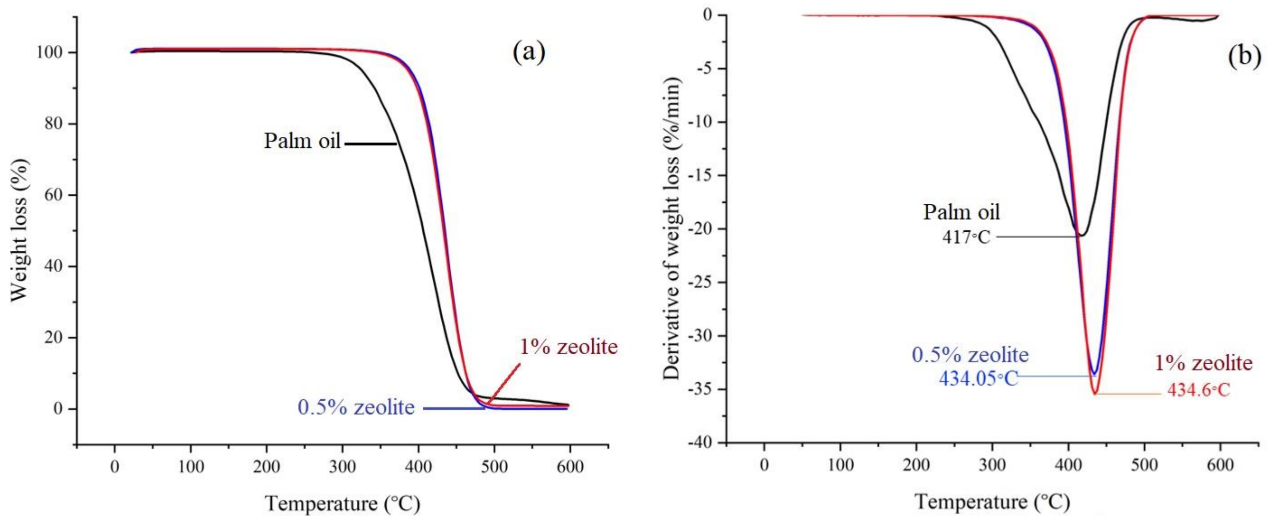

Fig.5. TGA of palm oil and nanofluid (a) weight loss and (b) derivative of weight loss.

Conclusion

The effect of NaA zeolite concentration suspended in palm oil was studied on the viscosity, viscosity index, density, and specific heat capacity. NaA zeolite with an average size 632 nm was added to palm oil at 0.25, 0.5, 0.75 and 1 wt%. The viscosity of palm oil at 40 °C and 100 °C was measured as 39.70, and 6.44 cSt, respectively. The viscosity of palm oil suspended with 0.25, 0.5, 0.75 and 1 wt% NaA zeolite at 40 °C was measured as 40.02, 40.06, 40.68, and 41.31 cSt, respectively and at 100 °C was 8.42, 8.44, 8.46, and 8.47 cSt, respectively. The highest viscosity index was 195 cSt when added with 0.5 wt% NaA zeolite. The density of palm oil slightly increased with increasing concentrations of NaA zeolite. The specific heat capacity of nanofluid is higher than that of palm oil. The results showed that the specific heat capacity of palm oil containing 0, 0.5% and 1% NaA zeolite by weight was 1.807, 2.078, and 2.136 J/g·°C, respectively. The experimental results showed that NaA zeolite allows palm oil to store heat energy better than palm oil, enabling it to release and absorb more heat during heat transfer. Thermogravimetric analysis, palm oil initiated to degrade at 263 °C, while the addition NaA zeolite in palm oil indicated that palm oil initiated to degrade at 350 °C. The shift in the degradation curve demonstrated that the nanofluid could withstand high temperatures. In addition, it showed that nanofluid could endure more heat and has a long service lift.

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