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EFFECT OF SiO_2 AND ZnO NANOPARTICLES TO INCREASE REFRIGERATION MACHINE PERFORMANCE

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Abstract
In this investigation, the impact of silicon dioxide (SiO_2) and zinc oxide (ZnO) nanoparticles on the performance of a refrigeration machine system was systematically examined. The focus was on evaluating the coefficient of performance (COP) concerning the utilization of a polyolester (POE) lubricant, R600a refrigerant, and distinct nanoparticles (SiO_2 and ZnO) within the refrigeration system. The nanoparticles were individually introduced into the R600a refrigerant in masses of 0.5 g, 1.0 g, and 1.5 g. The experimental outcomes demonstrated a noteworthy enhancement in COP with the addition of nanoparticles. Specifically, the introduction of 1.5 g of SiO_2 resulted in a substantial increase of 25.88% in COP, marking it as the most influential dosage. Similarly, the addition of 1.0 g of ZnO led to a significant COP increase of 13.6%, representing the optimal quantity for ZnO. Furthermore, the inclusion of 1.5 g of SiO_2 brought about a remarkable reduction in energy consumption, with a decrease of 25.58%, while 1.5 g of ZnO resulted in a notable 16.28% decrease in energy consumption. The experimental configuration involved the use of 20 g of refrigerant and 500 ml of POE lubricant. Comparative analysis demonstrated that the refrigeration system incorporating nanoparticles outperformed the conventional R600a refrigeration system devoid of nanoparticles. This study contributes valuable insights into the potential enhancements in refrigeration system efficiency through the strategic incorporation of SiO_2 and ZnO nanoparticles, offering a promising avenue for optimizing the performance of refrigeration technology.

Keywords: Nanoparticle, Nanofluid, Refrigerant, Refrigeration Engine Performance

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1. Introduction

Nanotechnology is a branch of science and technology strongly related to the rearrangement of particle sizes. In general, particle sizes can be distinguished by their diameter, i.e., coarse particles (10000–2500 nm), fine particles (2500–100 nm), and ultra-fine particles or nanoparticles (1–100 nm) [1].

A nano refrigerant is a type of nanofluid where the primary fluid is a conventional pure refrigerant. Experimental studies reported that nano refrigerants have higher thermal conductivity than conventional refrigerants. In addition, refrigeration systems using nano refrigerants have better performance than conventional pure refrigerants [2].

There are three main reasons that nanoparticles are used as part of refrigerant, i.e. (i) nanoparticles can increase the solubility between lubricant and refrigerant, (ii) nanoparticles increase thermal conductivity and heat transfer of the refrigerant, and (iii) nanoparticles disperse in the lubricant reducing the coefficient of friction and wear rate [3].

Senthilkumar et al. [4] conducted research on refrigerant R600a, mineral oil, and hybrid nanoparticles (SiO_2+ZnO) added to a refrigeration machine with a volume fraction of 0.4 g/L and 0.6 g/L and a refrigerant mass of 40 g and 60 g. The results for a mass of 40 g refrigerant with a volume fraction of 0.2 g/L and 0.4 g/L obtained an increase in COP of 30% and 45%, respectively, and for a mass of 60 g refrigerant with a volume fraction of 0.2 g/L and 0.4 g/L obtained an increase in COP of 8% and 31%, respectively.

Senthilkumar et al. [5] reported research on R600a refrigerant, POE lubricant, and SiO2 nanoparticles added to a refrigeration machine with volume fractions of 0.2 g/L, and 0.4 g/L and refrigerant mass fractions of 30 g, 40 g, and 60 g. For a volume fraction of 0.2 g/L and 0.4 g/L, the results of 30 g refrigerant found an increase of COP as 56% and 33%, respectively; results of 40 g refrigerant yielded COP increase of 11% and 50%,

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Fig. 1. Experimental test rig

respectively; and using 60 g refrigerant caused COP increase as 43% and 14%, respectively.

Sumit Shinde et al. [6] conducted a study on the effect of nanoparticles in vapor compression refrigeration systems (VCRS). This study used SiO_2 nanoparticles (15-20 nm) as an additive in refrigerants and lubricating oils. SiO_2 nanoparticles were added to refrigerant and lubricant to make nano refrigerant and mineral oil with volume fractions of 0.1, 0.2, and 0.3%. The results showed that the COP of the related volume fractions increased by 6.97, 9.9, and 12.68%.

Desai et al. [7] studied applying SiO_2 nanoparticles as a lubricant additive in VCRS. They observed that at SiO_2 concentrations of 1, 2, and 2.5% in POE oil, the compressor worked at 0.45, 0.4245, and 0.4327-kW, yielding COP increased by 7.61, 14.05, and 11.90%.

Sakshi Mishra et al. [8] conducted research on 20 - 50 nm CuO nanoparticles used as nano-lubricants for refrigeration test performance studies. Nanoparticles with a mass fraction of 0.30, 0.70, 1.05, and 1.40% were added to compressor oil and showed a significant increase in the refrigeration system's performance. Compressor work was reduced, and the COP of the refrigeration system increased.

Kuljeet Singh, et al. [9] has investigated the performance of nano refrigerant-based refrigeration systems (R134a + Al2O3). The study applied Al_2O_3 nanoparticles (diameter 20 nm) with 0.5 and 1.0% volume fractions dispersed in R134a refrigerant. Using 0.5% Al_2O_3, the COP increased by 8.5%, and applying 1.0% Al_2O_3, the COP was reduced by 5.4%; the effectiveness of the condenser and evaporator increased in the case of R134a + 0.5% Al_2O_3.

Based on the reports of previous studies, this investigation attempts to analyze refrigeration machine performance in terms of COP and energy consumption upon the addition of SiO_2 and ZnO nanoparticles in POE lubricants and R600a refrigerants in refrigeration systems. This study used SiO_2 and ZnO with mass fractions of 0.5, 1.0, and 1.5 g, respectively, 500 ml POE (polyol ester) lubricant and 20 g R600a refrigerant (isobutane). In this study, the discussion strongly emphasized chemical properties related to molecular interactions between nanoparticles, lubricants, and refrigerants, and therefore, it can be viewed as the strength of this study or any novelty that, in the authors' view, such comprehensive and thorough discussion was not reported previously. In addition, the reason for using isobutane refrigerant in this study is related to the issue of low global warming and zero potential for ozone depletion. Currently, this hydrocarbon is selected as the popular choice for commercial and domestic refrigerant purposes. Moreover, the reasons for using R600a are: (i) It has friendly environmental effects, (ii) It causes low energy consumption, (iii) It is compatible with any lubricant, and (iv) It shows good thermodynamic behavior.

2. Experimental and Procedures

Initially, the nanoparticles were mixed with POE lubricant and fed into the compressor as the refrigeration system. Due to its superiority and quality, the POE is commonly used as a lubricant in the refrigeration system [10-12]. The mixture of nanoparticles and lubricants significantly affects refrigeration machines' performance.

Fig. 1 shows the device used in this study. The working procedures are presented in consecutive steps as follows: (i) SiO_2 nanoparticles (0.5, 1.0 and 1.5 g) were mixed with 500 ml POE lubricant, (ii) The similar step was repeated for ZnO nanoparticles, (iii) The mixture of nanoparticles and POE lubricant was stirred using a magnetic stirrer for three hours until obtained a well-dispersed nanoparticles/POE lubricant oil, (iv) The mixture from step (iii) was ready for preparation and testing using an experimental test rig and the experimental test rig was cleaned from any dust and moisture using a vacuum pump, (v) The refrigeration machine performance was initially measured for pure R600a refrigerant (20 g) as the basic data, (vi) Nano lubricant with a mass of 0.5 g, 1.0 g, and 1.5 g in 500 ml oil was then added to 20 g refrigerant R600a using a filling line attached to refrigerant system, (vii) Temperatures in several parts of the experimental test rig were measured using a digital

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thermometer. The suction pressure and discharge pressure on the compressor were measured with a pressure gauge, (viii) The temperature data before entering and after leaving the compressor (T1 and T2) and before entering the expansion valve (T3), as well as pressure data before entering and after leaving compressor (P1 and P2) were all needed for enthalpy data in the calculation of RE, WC, and COP, respectively, (ix) The temperature and pressure data were taken at 30 min. for all experiments considering the results, and (x) The COP was obtained using the temperature and pressure data from step 9 above to get the enthalpy data, i.e., h1, h2, and h3 applying a thermodynamics & transport properties calculator.

The refrigerant effect (RE) values can be obtained from Equation 1;

$$RE = h2 - h1 \quad (1)$$

The work done by compressor (WC) values can be obtained from Equation 2;

$$WC = h3 - h2 \quad (2)$$

The COP values can be obtained from Equation 3;

$$COP = \frac{(h2-h1)}{(h3-h2)} \quad (3)$$

Some of the parameters used in this experiment are:

P1 = condensing pressure (bar)
P2 = evaporating pressure (bar)
T1 = inlet temperature compressor (°C)
T2 = outlet temperature compressor (°C)
T3 = inlet temperature expansion valve (°C)
h1 = inlet temperature compressor enthalpy (kJ/kg)
h2 = outlet temperature compressor enthalpy (kJ/kg)
h3 = inlet temperature expansion valve enthalpy (kJ/kg)
RE = refrigerant effect (kJ/kg)
WC = work done by compressor (kJ/kg)
COP = coefficient of performance

3. Results and Discussion

3.1 Results of Refrigeration Machine Performance

Table 1 shows the refrigerant effect (RE), work done by the compressor (WC), coefficient of performance (COP), and energy consumption (EC) from the testing results of the refrigeration machine with the addition of nanoparticles + POE oil in R600a refrigerant where test reading times were carried out at intervals 30 min.

3.2 Effect on Refrigerant Effect with the Addition of Nanoparticles and POE Oil

There was an increase in refrigerant effect with the addition of nanoparticles + POE oil, as shown in Table 2.

Table 1. Result of experiment with nanoparticles and POE oil

Description	RE kJ/kg	WC kJ/kg	COP	EC watt
Pure refrigerant (without nanoparticles)	238.9	104.73	2.28	43
Refrigerant + POE oil + nanoparticles SiO_2 (0.5 g)	249.81	100.86	2.48	41
Refrigerant + POE oil + nanoparticles SiO_2 (1.0 g)	248.25	93.63	2.65	36
Refrigerant + POE oil + nanoparticles SiO_2 (1.5 g)	257.81	89.83	2.87	32
Refrigerant + POE oil + nanoparticles ZnO (0.5 g)	243.16	101.38	2.4	41
Refrigerant + POE oil + nanoparticles ZnO (1.0 g)	248.1	95.73	2.59	36
Refrigerant + POE oil + nanoparticles ZnO (1.5 g)	247.04	96.85	2.55	36

Table 2. Increase of RE with addition of nanoparticles and POE oil

Description	Increase of refrigerant effect
Refrigerant + POE oil + nanoparticles SiO_2 (0.5 g)	4.57%
Refrigerant + POE oil + nanoparticles SiO_2 (1.0 g)	3.91%
Refrigerant + POE oil + nanoparticles SiO_2 (1.5 g)	7.92%
Refrigerant + POE oil + nanoparticles ZnO (0.5 g)	1.78%
Refrigerant + POE oil + nanoparticles ZnO (1.0 g)	3.85%
Refrigerant + POE oil + nanoparticles ZnO (1.5 g)	3.41%

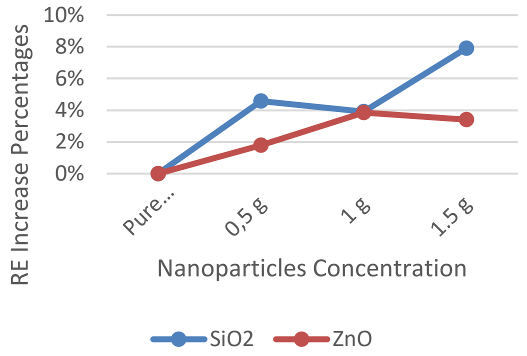

Fig. 2. % Refrigerant effect increase

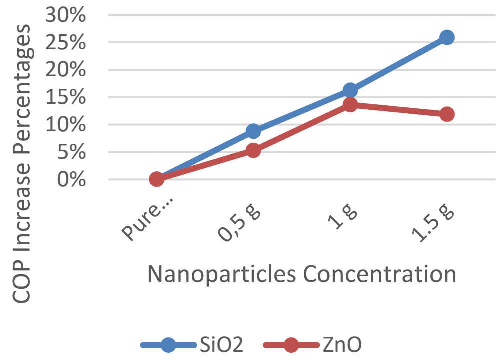

Fig. 4. COP increase percentages

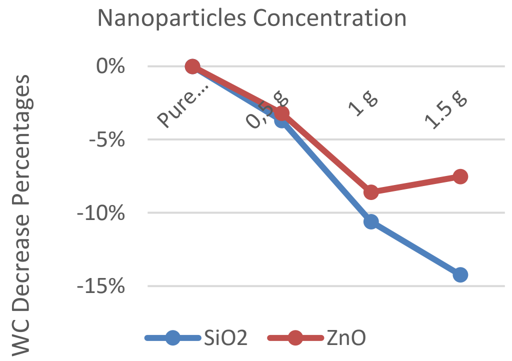

Fig. 3. % Work done by compressor decrease

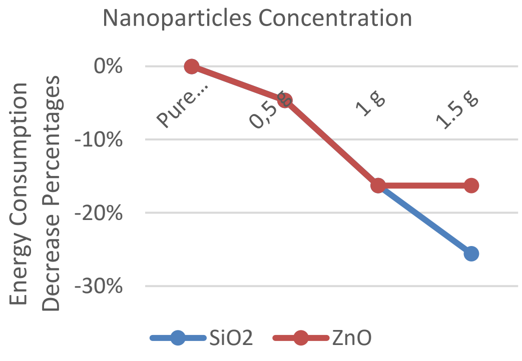

Fig. 5. Energy consumption decrease percentages

3.3 Effect of Work Done by Compressor with the Addition of Nanoparticles + POE Oil

There was a decrease in work done by compressor with the addition of nanoparticles + POE oil, as shown in Fig. 3.

3.4 Effect of COP with the Addition of Nanoparticles + POE Oil

There was an increase in COP with the addition of nanoparticles + POE oil, as shown in Fig. 4.

Fig. 2 shows the effect of nanoparticle addition (SiO_2 and ZnO) on refrigerant effect based on data from Table 2. Fig. 3 shows the effect of both SiO_2 and ZnO additions on work done by the compressor based on data Table 3. Fig. 4 shows the effect of both SiO_2 and ZnO addition on COP based on data from Table 4, and Fig. 5 shows the effect of SiO_2 and ZnO addition upon energy consumption using data from Table 5.

3.5 Effect of Energy Consumption with Addition of Nanoparticles and POE Oil

There was a decrease in energy consumption with the addition of nanoparticles + POE oil, as shown in Fig. 5.

It should be noted that the POE lubricant displays as an emulsifier, in this case, for inorganic nanoparticles (SiO_2 and ZnO) and R600a refrigerant. R600a refrigerant is a commercial name for isobutane as an organic alkane. The important point in this matter is that all three components, i.e., the POE lubricant, inorganic nanoparticles, and R600a refrigerant, should form a soluble nanofluid. Therefore, the rule “like dissolves like” should be fulfilled; that is, the polar component dissolves in a polar solvent, or the non-polar component dissolves in a non-polar solvent. POE lubricant is a semi-organic component with a chemical formula similar to polyester, which is a polar organic solvent. Thus, the POE lubricant may increase the solubility of inorganic nanoparticles (SiO_2 and ZnO). As already mentioned above, nanoparticles have tremendous properties with regard to their thermal conductivity and heat transfer, and therefore, nanoparticles may reduce the friction effect [3,5-6].

It is not surprising that the addition of nanoparticles (SiO_2 and ZnO) increases the heat transfer, yielding increased refrigeration machine performance in terms of COP (Table 2 and Table 4). Since the nanoparticles reduced the friction factor between the components involved [4, 13-14], as predicted, the addition of nanoparticles in this refrigeration system may decrease the work done by the compressor and energy consumption (Table 3 and Table 5).

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Table 3. Decrease of work done by compressor with addition nanoparticles and POE oil

Description	Increase of work done by compressor
Refrigerant + POE oil + nanoparticles SiO_2 (0.5 g)	-3.70%
Refrigerant + POE oil + nanoparticles SiO_2 (1.0 g)	-10.60%
Refrigerant + POE oil + nanoparticles SiO_2 (1.5 g)	-14.23%
Refrigerant + POE oil + nanoparticles ZnO (0.5 g)	-3.20%
Refrigerant + POE oil + nanoparticles ZnO (1.0 g)	-8.59%
Refrigerant + POE oil + nanoparticles ZnO (1.5 g)	-7.52%

Table 4. Increase in COP with addition of nanoparticle and POE oil

Description	Increase of COP
Refrigerant + POE oil + nanoparticles SiO_2 (0.5 g)	8.77%
Refrigerant + POE oil + nanoparticles SiO_2 (1.0 g)	16.23%
Refrigerant + POE oil + nanoparticles SiO_2 (1.5 g)	25.88%
Refrigerant + POE oil + nanoparticles ZnO (0.5 g)	5.26%
Refrigerant + POE oil + nanoparticles ZnO (1.0 g)	13.60%
Refrigerant + POE oil + nanoparticles ZnO (1.5 g)	11.84%

Table 5. Decrease in Energy Consumption with Addition Nanoparticles + POE Oil

Description	Decrease in energy consumption
Refrigerant + POE oil + nanoparticles SiO_2 (0.5 g)	-4.65%
Refrigerant + POE oil + nanoparticles SiO_2 (1.0 g)	-16.28%
Refrigerant + POE oil + nanoparticles SiO_2 (1.5 g)	-25.58%
Refrigerant + POE oil + nanoparticles ZnO (0.5 g)	-4.65%
Refrigerant + POE oil + nanoparticles ZnO (1.0 g)	-16.28%
Refrigerant + POE oil + nanoparticles ZnO (1.5 g)	-16.28%

The fluctuated results and different yields of refrigerant effect (RE), work done by the compressor (WC), and refrigerant machine performance (COP), as well as energy consumption (EC) between SiO_2 and ZnO nanoparticles as shown by Figs 2–5, are strongly influenced by different particle sizes between SiO_2 (≈ 50 nm) and ZnO (≈ 30 nm) and electronic configuration of those oxides. However, with regard to Figs 2–4, after the addition of 1.5g ZnO, the refrigeration machine performance showed a decline in terms of RE, WC, and COP; this finding is related to a higher quantity of polar ZnO particles yielding more particles collisions increasing friction effect reducing thermal conductivity. This phenomenon was not shown for SiO_2 due to the difference in polarity between ZnO and SiO_2.

Moreover, both SiO_2 and ZnO have amphoteric properties that can act as an acid in a base medium or as a base in an acid medium. Therefore, both types of nanoparticles have more flexibility in molecular interactions. Previous studies [4-5,15-16] reported the utilization of SiO_2, ZnO, and Al_2O_3, classified as flexible amphoteric oxides.

It should be noted that silicon (Si) is attributed to IVA group elements, while zinc (Zn) is attributed to IIB group elements in the Periodic Table. Different particle sizes and group elements between silicon and zinc significantly influence the electron affinity and interaction effect, which, not surprisingly, yields different results in refrigeration machine performance and energy consumption.

This study shows that both 1.5 g SiO_2 and 1.0 g ZnO yield the highest refrigerant machine performance based on the experimental results. In the outcome, software modeling can be advantageous for the optimization of the research results. A previous report [17] applied the finite element method to optimize cast wheel design for motorcycles. With regard to engineering matters, Wibowo and Sebayang [18] applied HOMER software for the optimization of solar wind hybrid power design. Software modeling is sophisticated for design and optimization on reasons of fast, precise, and accurate.

4. Conclusion

Interesting features can be withdrawn from this study related to the role of nanoparticles in enhancing better results in refrigeration machine performance in terms of refrigerant efficiency, work done, and coefficient of performance, as well as energy consumption. The tremendous properties of nanoparticles are advantageous for enhancing refrigerant performance. This phenomenon is related to molecular interactions between inorganic amphoteric oxides (SiO_2 and ZnO), organic polyol ester lubricant, and organic isobutane refrigerant following the rule of solubility to yield more soluble nanofluid to increase heat transfer and decrease

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friction effects and wear rate.

References

[1] Gunasekaran, K., Nirmala, M., Raja, K., & Saravanakumar, A. (2017). Characterization and application of biosynthesized silver nanoparticles from Melia Dubia leaves. *Indian Journal of Geology and Marine Science*, 46(8), 1715–1720.

[2] Jiang, W., Ding, G., & Peng, H. (2009). Measurement and model on thermal Conductivities of carbon nanotube nanorefrigerants. *International Journal of Thermal Sciences*, 48(6), 1108-1115.

[3] Alawi, O. A., Sidik, N. A. C, & Mohammed, H. A. (2014). A comprehensive review of fundamentals, preparation and applications of nanorefrigerants. *International Communications in Heat and Mass Transfer*, 54, 81-95.

[4] Senthilkumar, A, Sahaluddeen, M, Noushad, M. N., & Musthafa, M. (2020). Experimental investigation of ZnO / SiO_2 hybrid nano-lubricant in R600a vapour compression refrigeration system. *Materials Today: Proceedings*, 45, 6087-6093.

[5] Senthilkumar, A, Dhas, A. A. G., Athimoolam, A., & Antony, A. R. (2022). Evaluation of R600a blended with various quantities of CuO, Al2O3 and SiO_2 nanoparticles. *Zaštita Materijala*, 63(4), 463-476.

[6] Sumit, S. & Sanket, P. (2017). Enhancement of COP using Nanoadditives in Domestic Refrigerator. *International Engineering Research Journal (IERJ)*, 2(10), 4311-4316.

[7] Desai, N. S. & Patil P. R. (2015). Application of SiO_2 Nano- particles as Lubricant Additive in VCRS: An Experimental Investigation. *Asian Review of Mechanical Engineering*, *4*(1), 1-6.

[8] Sakshi M. & Harge, C. G. (2019). Effect of Addition of Different Mass Fractions of CuO Nano particles in Compressor oil upon COP of the Refrigeration System. *International Journal of Recent Technology and Engineering (IJRTE)*, 8(3), 3732-3736.

[9] Singh, K. & Kundan, L. (2014). An Investigation into the Performance of a Nano refrigerant (R134a + Al_2O_3) Based Refrigeration System. In *4th International Conference on Advances in Materials and Manufacturing Technology*.

[10] Azo Nano (2013). *Silicon Dioxide (SiO_2) Nanoparticles – Properties & Applications*. Available from: https://www.azonano.com/ article.aspx?ArticleID 3398 [Accessed: 6th November 2022].

[11] Azo Nano (2013). *Zinc Oxide (ZnO) Nanoparticles – Properties & Applications*. Available from: https://www.azonano.com/ article.aspx?ArticleID=3348 [Accessed: 6th November 2022].

[12] Desai, N. S. & Patil P. R. (2015). Application of SiO_2 Nano- particles as Lubricant Additive in VCRS: An Experimental Investigation. *Asian Review of Mechanical Engineering*, *4*(1), 1-6..

[13] Kushwaha, P. K., Shrivastava, P., & Shrivastava, A. K. (2016). Experimental Study of Nanorefrigeran (R134a + Al2O3) Based on Vapor Compression Refrigeration System. *International Journal Of Mechanical And Production Engineering*, *4*(3), 90-95.

[14] Pawale, K. T., Dhumal, A. H., & Kerkal, G. M. (2017). Performance Analysis of VCRS with Nano-Refrigeran. *International Research Journal of Engineering and Technology*, *4*(4), 1031-1037.

[15] Selimefendigil, F. (2019). Experimental investigation of nano compressor oil effect on the cooling performance of a vapor-compression refrigeration system. *Journal of Thermal Engineering*, *5*(1), 100-104.

[16] Sachindra, J. D. (2017). Review on Enhancement of COP of Refrigeration system by Inclusion of Nano Particles in Refrigerant. *International Journal of Advance Engineering and Research Development (IJAERD),* 4(8), 1-6.

[17] Kurniawan, R. N. A, Romahadi, D,, Fitri, M., & Karim, M. R. (2022). Implementation of the finite element method in SolidWorks to optimize the front cast wheel design for motorcycles. *International Journal of Innovation in mechanical Engineering & Advances Materials,* 4(3), 66-73.

[18] Wibowo, I. A. & Sebayang, D. (2015). Optimization of solar wind diesel hybrid power system design using HOMER. *International Journal of Innovation in mechanical Engineering & Advances Materials*, 1(1), 27-31.