PERFORMANCE OF NANOLUBRICANTS AND R1234YF IN AUTOMOTIVE AIR CONDITIONING SYSTEM

SHARIF BIN MOHD ZAKI

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

(Supervisor's Signature)

Full Name : DR. WAN AZMI BIN WAN HAMZAH

Position : ASSOCIATE PROFESSOR

Date : 25 OCTOBER 2021

(Co-supervisor's Signature)

Full Name : DR. RIZALMAN MAMAT

Position : PROFESSOR

Date : 25 OCTOBER 2021

(Field supervisor's Signature)

Full Name : IR DR IRNIE AZLIN ZAKARIA

Position : SENIOR LECTURER

Date : 25 OCTOBER 2021

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : SHARIF BIN MOHD ZAKI

ID Number : PMA17001

Date : 25 OCTOBER 2021

PERFORMANCE OF NANOLUBRICANTS AND R1234YF IN AUTOMOTIVE AIR CONDITIONING SYSTEM

SHARIF BIN MOHD ZAKI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

College of Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2021

ACKNOWLEDGEMENTS

First, I would like to express my gratefulness to ALLAH SWT for allowing me to learn and gain new experiences at Universiti Malaysia Pahang. Therefore, I can write and complete this meaningful thesis.

In setting up this thesis, I was lucky enough to get help from numerous individuals to finish this work. In the first place, I would like to express my gratitude to my project supervisor, co-supervisor and field supervisor; Associate Professor Dr Wan Azmi bin Wan Hamzah, Professor Dr Rizalman bin Mamat and Ir. Dr Irnie Azlin Zakaria for their germinal thoughts, unwavering support, essential directions, advice and inspiration. I am also would like to thank my fellow lab teammates; Dr Mohamad Redhwan bin Abd. Aziz, Dr Nurul Nadia binti Mohd Zawawi, Dr Khamisah binti Abdul Hamid, Mr. Anwar Ilmar Ramadhan, Ms. Sharifah Norsakinah binti Syed Zainal Abidin and Mr. Ts Mohd Hamisa Bin Abdul Hamid. They helped me in many things, and without their constant helpful thoughts, I may not complete this work.

To wrap things up, I recognize without unending adoration and constant backing from my family, I would not be here. My mother; Sharipah binti Abdul Karim and all my kin, with their dependable help, presence, tolerance, and understanding, were inexorable to make this work a conceivable inspiration and urged me to achieve better. I cannot find the fitting words that could appropriately depict my gratefulness for their dedication, backing and confidence in my capacity to achieve my goals.

Thank you all.

ABSTRAK

Kini, gas penyaman udara R1234yf telah digunakan dalam sistem penyaman udara automotif (AAC) bagi menggantikan R134a; yang telah diketahui bahawa R1234yf mempunyai potensi pemanasan global (GWP) yang tinggi dan kadar penipisan ozon sifar (ODP). Walau bagaimanapun, sistem AAC yang menggunakan R1234yf mempunyai prestasi yang lebih rendah berbanding sistem sebelum ini yang mengunakan R134a. Sebagai langkah penyelesaian, nano pelincir telah digunakan dengan harapan untuk meningkatkan prestasi sistem AAC-R1234yf. Objektif kajian ini adalah untuk mencirikan sifat terma-fizikal nano pelincir dan menyiasat prestasi sistem AAC yang menggunakan nano pelincir dan R1234yf sebagai bendalir kerja; melalui kaedah kajian eksperimen dan juga simulasi berkomputer. Nano pelincir Al_2O_3/PAG, SiO_2/PAG, dan Al_2O_3-SiO_2/PAG dihasilkan dengan mencampurkan nano partikel ke dalam pelincir asal iaitu PAG ND12 melalui kaedah penyediaan nano bendalir dua langkah. Kestabilan nano pelincir telah diuji menggunakan kaedah pengujian *Ultraviolet-Visible* (UV-Vis) *spectrophotometer* 4 langkah dan potensi zeta. Sifat terma-fizikal seperti kelikatan dinamik dan kekonduksian haba untuk nano pelincir novel ini telah diukur. Penyelidikan mengenai prestasi sistem AAC dilakukan menggunakan nano pelincir dengan campuran Al_2O_3/PAG, SiO_2/PAG, dan Al_2O_3-SiO_2/PAG pada kepekatan isipadu yang berbeza dan pelbagai keadaan operasi. Prestasi sistem AAC dinilai dengan mengukur tahap penyerapan haba, kerja pemampat dan pekali prestasi (COP). Nano pelincir Al_2O_3-SiO_2/PAG dengan prestasi terbaik dalam kajian eksperimen dipilih untuk penilaian lebih lanjut dalam kajian simulasi. Analisis simulasi AAC dengan suis terma statik menggunakan R1234yf dan nano pelincir Al_2O_3-SiO_2/PAG pada kepekatan optimum dilakukan untuk menilai tingkah laku sistem AAC dalam keadaan kenderaan sebenar. Hasil dari analisis kestabilan menunjukkan bahawa c jenis Al_2O_3/PAG, SiO_2/PAG, dan Al_2O_3-SiO_2/PAG mempunyai kestabilan yang sangat baik dengan pemendapan visual yang minimum, mempunyai nisbah kepekatan lebih dari 70% setelah ditinggalkan selama 6 bulan dan juga mempunyai potensi zeta lebih besar daripada 60 mV. Selanjutnya, sifat terma-fizikal nano pelincir menunjukkan penambaikan dengan peningkatan kepekatan isipadu. Nano pelincir ini menunjukkan beberapa sifat penebalan ricih pada kadar ricih yang rendah tetapi menunjukkan tingkah laku *Newtonian* pada kadar ricih yang lebih tinggi. Kekonduksian haba nano pelincir Al_2O_3/PAG, SiO_2/PAG dan Al_2O_3-SiO_2/PAG menurun dengan peningkatan suhu tetapi menaik dengan peningkatan kepekatan isipadu. Nano pelincir terbaik adalah Al_2O_3-SiO_2/PAG kerana mempunyai daya pengaliran haba tertinggi dengan nilai kelikatan pertengahan antara Al_2O_3/PAG dan SiO_2/PAG. Sistem AAC-SiO_2 mempunyai prestasi kapasiti penyejukan yang lebih baik dengan peningkatan sehingga 15.7% pada kepekatan 0.01% tetapi sedikit penurunan daripada aspek penggunaan kuasa dan prestasi COP. Sementara itu, sistem AAC-Al_2O_3 menunjukkan prestasi yang lebih baik daripada sistem AAC-SiO_2 daripada aspek penggunaan kuasa dan peningkatan COP dengan pengurangan purata 27.1% dan peningkatan purata 9.8%, pada kepekatan 0.05%. COP telah ditambahbaik lagi untuk sistem AAC-Al_2O_3-SiO_2 dengan kenaikan purata 12.01% dalam semua keadaan ujian. Simulasi model dinamik mengesahkan bahawa prestasi sistem AAC-Al_2O_3-SiO_2 lebih baik daripada sistem asal dengan pengunaan tenaga yang lebih sedikit dan kapasiti penyejukan yang lebih tinggi. Sistem AAC-Al_2O_3-SiO_2 mempunyai frekuensi kitaran suhu yang lebih rendah berbanding dengan sistem AAC dengan PAG. Kesimpulannya, nano pelincir Al_2O_3-SiO_2/PAG disyorkan untuk digunakan dalam sistem AAC dengan penyejuk R1234yf untuk peningkatan prestasi sistem secara keseluruhan.

ABSTRACT

Currently, R1234yf refrigerant has been used to replace R134a refrigerant in automotive air conditioning (AAC) systems due to its low global warming potential (GWP) and zero ozone depletion potential (ODP). However, the low performance of the vapour compression in the AAC system using the R1234yf has been a significant hindrance. Hence, a passive method using nanolubricants is proposed to enhance the performance of an AAC system operating with R1234yf. The objectives of this study are to characterize the nanolubricants for AAC system and investigate the performance of AAC system using nanolubricants and R1234yf under experimental and numerical simulated conditions. Aluminium oxide (Al_2O_3) and Silicon dioxide (SiO_2) nanoparticles are dispersed in PAG ND12 lubricant. Al_2O_3/PAG, SiO_2/PAG, and Al_2O_3-SiO_2/PAG nanolubricants were prepared by two-step method of preparation. The stability of the nanolubricants was confirmed by 4-Step Ultraviolet-Visible (UV-Vis) spectrophotometer and zeta potential. Thermo-physical properties namely dynamic viscosity and thermal conductivity evaluation were employed to characterize the novel nanolubricants with PAG ND12 based lubricant. The experimental investigation on the performance of automotive air conditioning system with R1234yf was undertaken for the Al_2O_3/PAG, SiO_2/PAG, and Al_2O_3-SiO_2/PAG nanolubricants at different volume concentrations and various operating conditions. The performance of the AAC system is evaluated by measuring the degree of heat absorption, compressor work and coefficient of performance (COP). The Al_2O_3-SiO_2/PAG nanolubricants with the best performance in the experimental study was selected for further evaluation in simulation study. The simulation analysis of AAC with thermostatic switch using R1234yf and Al_2O_3-SiO_2/PAG nanolubricants at optimum concentration was done to evaluate the behaviour of AAC system in real vehicle conditions. The results from the stability analysis show that the Al_2O_3/PAG, SiO_2/PAG, and Al_2O_3-SiO_2/PAG nanolubricants was confirmed in excellent stability condition for more than 6 months with minimum visual sedimentation, more than 70% concentration ratio and zeta potentials greater than 60 mV. Further, the thermo-physical properties of the nanolubricants showed improvement with increasing of volume concentration. These nanolubricants exhibit some shear thickening properties at low shear rates but show Newtonian behaviour at higher shear rates onwards. The thermal conductivity of the Al_2O_3/PAG, SiO_2/PAG and Al_2O_3-SiO_2/PAG nanolubricants were decreased with increasing temperature but increased with increasing of volume concentration. Al_2O_3-SiO_2/PAG hybrid nanolubricants outperformed others with highest thermal conductivity and intermediate viscosity value between Al_2O_3/PAG and SiO_2/PAG nanolubricants. The AAC-SiO_2 system has better cooling capacity performance with enhancement up to 15.7% at 0.01% concentration but slightly decrease in terms of power consumption and COP performance. Meanwhile the AAC-Al_2O_3 system performed better than AAC-SiO_2 system in terms of power consumption and COP improvement with 27.1% average reduction and 9.8% average enhancement, respectively for 0.05% concentration. The COP was improved further for AAC-Al_2O_3-SiO_2 hybrid system with average increment of 12.01% in all test conditions. The dynamic model simulation was confirmed the performance of Al_2O_3-SiO_2/PAG hybrid nanolubricants better than original system with less energy, lower power consumption and higher cooling capacity. The AAC system operating with hybrid nanolubricants has a lesser temperature cycling frequency compared to the AAC system with PAG lubricant. As a conclusion, Al_2O_3-SiO_2/PAG hybrid nanolubricants and R1234yf is recommended for application in AAC system with the improvement of overall system performance.

TABLE OF CONTENT

REFERENCES

Abbas, M., Walvekar, R. G., Hajibeigy, M. T., & Javadi, F. S. (2013). *Efficient air-condition unit by using nano-refrigerant.* Paper presented at the 1st Engineering Undergraduate Research Catalyst Conference, Malaysia.

Adelekan, D. S., Ohunakin, O. S., Babarinde, T. O., Odunfa, M. K., Leramo, R. O., Oyedepo, S. O., & Badejo, D. C. (2017). Experimental performance of LPG refrigerant charges with varied concentration of TiO_2 nano-lubricants in a domestic refrigerator. *Case Studies in Thermal Engineering, 9*, 55-61.

Adelekan, D. S., Ohunakin, O. S., Gill, J., Atayero, A. A., Diarra, C. D., & Asuzu, E. A. (2019). Experimental performance of a safe charge of LPG refrigerant enhanced with varying concentrations of TiO_2 nano-lubricant in a domestic refrigerator. *Journal of Thermal Analysis and Calorimetry, 136*(6), 2439-2448.

AG, D. (2012). New findings concerning the risks of the new R1234yf refrigerant: Mercedes-Benz wishes to continue using the tried-and-tested R134a refrigerant in passenger cars. from goo.gl/Zou2V

Akhavan-Behabadi, M. A., Sadoughi, M. K., Darzi, M., & Fakoor-Pakdaman, M. (2015). Experimental study on heat transfer characteristics of R600a/POE/CuO nano-refrigerant flow condensation. *Experimental Thermal and Fluid Science, 66*, 46-52.

Al-Ghussain, L. (2019). Global warming: review on driving forces and mitigation. *Environmental Progress & Sustainable Energy, 38*(1), 13-21.

Alawi, O. A., & Sidik, N. A. C. (2015). Applications of nanorefrigerant and nanolubricants in refrigeration, air-conditioning and heat pump systems: A review. *International Communications in Heat and Mass Transfer, 68*, 91-97.

Alawi, O. A., Sidik, N. A. C., & Kherbeet, A. S. (2015). Nanorefrigerant effects in heat transfer performance and energy consumption reduction: A review. *International Communications in Heat and Mass Transfer, 69*, 76-83.

Ali, M. K. A., Hou, X., & Abdelkareem, M. A. A. (2020). Anti-wear properties evaluation of frictional sliding interfaces in automobile engines lubricated by copper/graphene nanolubricants. *Friction, 8*(5), 905-916.

Aminullah, A. R. M., Azmi, W. H., Redhwan, A. A. M., Sharif, M. Z., Zawawi, N. N. M., Kadirgama, K., & Ashraf, M. N. S. (2018). Tribology investigation of automotive air condition (AAC) compressor by using Al2O3/PAG nanolubricants. *Journal of Mechanical Engineering, 5*(1), 49-61.

Anwar, Z., Palm, B., & Khodabandeh, R. (2015). Flow boiling heat transfer, pressure drop and dryout characteristics of R1234yf: Experimental results and predictions. *Experimental Thermal and Fluid Science, 66*, 137-149.

Aprea, C., & Maiorino, A. (2008). An experimental evaluation of the transcritical CO2 refrigerator performances using an internal heat exchanger. *International Journal of Refrigeration, 31*(6), 1006-1011.

Aral, M. C., Suhermanto, M., & Hosoz, M. (2020). Performance evaluation of an automotive air conditioning and heat pump system using R1234yf and R134a. *Science and Technology for the Built Environment*(just-accepted), 1-37.

Asadi, M., & Asadi, A. (2016). Dynamic viscosity of MWCNT/ZnO–engine oil hybrid nanofluid: An experimental investigation and new correlation in different temperatures and solid concentrations. *International Communications in Heat and Mass Transfer, 76*, 41-45.

ASHRAE. Standard 41.9-2000.

Assael, M., Dalaouti, N., Griva, A., & Dymond, J. (1999). Viscosity and thermal conductivity of halogenated methane and ethane refrigerants. *International Journal of Refrigeration, 22*(7), 525-535.

Azmi, W. H., Sharif, M. Z., Yusof, T. M., Mamat, R., & Redhwan, A. A. M. (2017a). Potential of nanorefrigerant and nanolubricants on energy saving in refrigeration system–A review. *Renewable and Sustainable Energy Reviews, 69*, 415-428.

Azmi, W. H., Sharma, K., Sarma, P., Mamat, R., Anuar, S., & Rao, V. D. (2013). Experimental determination of turbulent forced convection heat transfer and friction factor with SiO_2 nanofluid. *Experimental Thermal and Fluid Science, 51*, 103-111.

Azmi, W. H., Sharma, K. V., Mamat, R., Najafi, G., & Mohamad, M. S. (2016). The enhancement of effective thermal conductivity and effective dynamic viscosity of nanofluids – A review. *Renewable and Sustainable Energy Reviews, 53*, 1046-1058.

Azmi, W. H., Usri, N. A., Mamat, R., Sharma, K. V., & Noor, M. M. (2017b). Force convection heat transfer of Al_2O_3 nanofluids for different based ratio of water: Ethylene glycol mixture. *Applied Thermal Engineering, 112*, 707-719.

Bartelt, K., Park, Y., Liu, L., & Jacobi, A. (2008, July 14-17). *Flow-boiling of R-134a/POE/CuO nanofluids in a horizontal tube.* Paper presented at the International Refrigeration and Air Conditioning Conference, Purdue.

Beer, A. (1852). Determination of the absorption of red light in colored liquids. *Ann. Phys. Chem, 86*, 78-88.

Belman-Flores, J. M., Rodríguez-Muñoz, A. P., Pérez-Reguera, C. G., & Mota-Babiloni, A. (2017). Experimental study of R1234yf as a drop-in replacement for R134a in a domestic refrigerator. *International Journal of Refrigeration, 81*(Supplement C), 1-11.

Bentrcia, M., Alshatewi, M., & Omar, H. (2017). Developments of vapor-compression systems for vehicle air-conditioning: A review. Advances in Mechanical Engineering, 9(8), 1687814017717186.

Besagni, G., Mereu, R., & Inzoli, F. (2016). Ejector refrigeration: A comprehensive review. *Renewable and Sustainable Energy Reviews, 53*, 373-407.

Bi, S., Guo, K., Liu, Z., & Wu, J. (2011). Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as working fluid. *Energy Conversion and Management, 52*(1), 733-737.

Bi, S., & Shi, L. (2007). Experimental investigation of a refrigerator with a nano-refrigerant. *Qinghua Daxue Xuebao/Journal of Tsinghua University, 47*(11), 2002-2005.

Bi, S. S., Shi, L., & Zhang, L. L. (2008). Application of nanoparticles in domestic refrigerators. *Applied Thermal Engineering, 28*(14), 1834-1843.

Bianco, V., Manca, O., Nardini, S., & Vafai, K. (2015). *Heat transfer enhancement with nanofluids*. US: CRC Press.

Bobbo, S., Fedele, L., Fabrizio, M., Barison, S., Battiston, S., & Pagura, C. (2010). Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility. *International Journal of Refrigeration, 33*(6), 1180-1186.

Bobbo, S., Zilio, C., Scattolini, M., & Fedele, L. (2014). R1234yf as a substitute of R134a in automotive air conditioning. Solubility measurements in two commercial PAG oils. *International Journal of Refrigeration, 40*, 302-308.

Bordarier, P., Rousseau, B., & Fuchs, A. H. (1998). A model for the static friction behaviour of nanolubricated contacts. *Thin Solid Films, 330*(1), 21-26.

Boumaraf, L., Haberschill, P., & Lallemand, A. (2014). Investigation of a novel ejector expansion refrigeration system using the working fluid R134a and its potential substitute R1234yf. *International Journal of Refrigeration, 45*, 148-159.

Brinkman, H. (1952a). The viscosity of concentrated suspensions and solutions. *The Journal of Chemical Physics, 20*(4), 571-571.

Brinkman, H. C. (1952b). The viscosity of concentrated suspensions and solutions. *The Journal of Chemical Physics, 20*(4), 571-571.

Brown, J. S., Zilio, C., & Cavallini, A. (2010). Thermodynamic properties of eight fluorinated olefins. *International Journal of Refrigeration, 33*(2), 235-241.

Brown, W. L. (1993). Polyalkylene glycols. *CRC Handbook of Lubrication and Tribology, 3*, 253-267.

Buongiorno, J., Venerus, D. C., Prabhat, N., McKrell, T., Townsend, J., Christianson, R., Tolmachev, Y. V., Keblinski, P., Hu, L. W., & Alvarado, J. L. (2009). A benchmark study on the thermal conductivity of nanofluids. *Journal of Applied Physics, 106*(9), 094312.

Buonomo, B., Manca, O., Marinelli, L., & Nardini, S. (2015). Effect of temperature and sonication time on nanofluid thermal conductivity measurements by nano-flash method. *Applied Thermal Engineering, 91*, 181-190.

Calm, J. M. (2008). The next generation of refrigerants–Historical review, considerations, and outlook. *International Journal of Refrigeration, 31*(7), 1123-1133.

Chandrasekar, M., Suresh, S., & Bose, A. C. (2010). Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al_2O_3/water nanofluid. *Experimental Thermal and Fluid Science*, *34*(2), 210-216.

Chang, H., Jwo, C., Fan, P., & Pai, S. (2007). Process optimization and material properties for nanofluid manufacturing. *The International Journal of Advanced Manufacturing Technology, 34*(3), 300-306.

Chang, H., Wu, Y., Chen, X., & Kao, M. (2000). Fabrication of Cu based nanofluid with superior dispersion. *National Taipei University of Technology Journal, 5*, 201-208.

Chen, J., Jarall, S., Havtun, H., & Palm, B. (2015). A review on versatile ejector applications in refrigeration systems. *Renewable and Sustainable Energy Reviews, 49*, 67-90.

Chen, J., Zhao, Y., & Qi, Z. (2011). New developments in mobile air conditioning systems in China. *Frontiers of Energy and Power Engineering in China, 5*(1), 53-58.

Chen, Y., Yang, Z., Liu, H., Ge, Y., Zhai, R., Feng, B., Lv, Z., & Zhao, W. (2020). Experimental study on the contribution of R161 and R1234yf to the miscibility of R32 with lubricating oils. *Applied Thermal Engineering*, 115338.

Cho, H., Lee, H., & Park, C. (2013). Performance characteristics of an automobile air conditioning system with internal heat exchanger using refrigerant R1234yf. *Applied Thermal Engineering, 61*(2), 563-569.

Cho, H., & Park, C. (2016). Experimental investigation of performance and exergy analysis of automotive air conditioning systems using refrigerant R1234yf at various compressor speeds. *Applied Thermal Engineering, 101*, 30-37.

Cho, H., Ryu, C., Kim, Y., & Kim, H. Y. (2005). Effects of refrigerant charge amount on the performance of a transcritical CO2 heat pump. *International Journal of Refrigeration, 28*(8), 1266-1273.

Choi, U. S. (1995). Enhancing thermal conductivity of fluids with nanoparticles. In D. A. Siginer & H. P. Wang (Eds.), *Developments and Applications of Non-Newtonian Flows* (Vol. FED-vol. 231/MD-Vol. 66, pp. 99–105). New York: American Society of Mechanical Engineers (ASME).

Chopkar, M., Kumar, S., Bhandari, D. R., Das, P. K., & Manna, I. (2007). Development and characterization of Al_2Cu and Ag_2Al nanoparticle dispersed water and ethylene glycol based nanofluid. *Materials Science and Engineering : B, 139*(2), 141-148.

Chung, S. J., Leonard, J. P., Nettleship, I., Lee, J.-K., Soong, Y., Martello, D. V., & Chyu, M. K. (2009). Characterization of ZnO nanoparticle suspension in water: effectiveness of ultrasonic dispersion. *Powder Technology, 194*(1), 75-80.

Contreras, E. M. C., Oliveira, G. A., & Bandarra Filho, E. P. (2019). Experimental analysis of the thermohydraulic performance of graphene and silver nanofluids in automotive cooling systems. *International Journal of Heat and Mass Transfer, 132*, 375-387.

Corr, S., Randles, S. J., & Gibb, P. T. (2005). Lubricant compositions: Google Patents.

Coumaressin, T., & Palaniradja, K. (2014). Performance analysis of a refrigeration system using nano fluid. *International Journal of Advanced Mechanical Engineering, 4*(4), 459-470.

Cremaschi, L., Wong, T., & Bigi, A. A. M. (2014). *Thermodynamic and heat transfer properties of Al_2O_3 nanolubricants.* Paper presented at the International Refrigeration And Air Conditioning Conference, Purdue.

Daly, S. (2011). *Automotive air conditioning and climate control system*
s: Elsevier.

Datta, S. P., Das, P. K., & Mukhopadhyay, S. (2014). Effect of refrigerant charge, compressor speed and air flow through the evaporator on the performance of an automotive air conditioning system.

De Bruijn, H. (1942). The viscosity of suspensions of spherical particles.(The fundamental η-c and φ relations). *Recueil des travaux chimiques des Pays-Bas, 61*(12), 863-874.

Del Col, D., Bortolin, S., Torresin, D., & Cavallini, A. (2013). Flow boiling of R1234yf in a 1 mm diameter channel. *International Journal of Refrigeration, 36*(2), 353-362.

Del Col, D., Torresin, D., & Cavallini, A. (2010). Heat transfer and pressure drop during condensation of the low GWP refrigerant R1234yf. *International Journal of Refrigeration, 33*(7), 1307-1318.

DENSO-Europe, B. V. (2017). Compressor oil and refrigerant: Mixing old and new. 1st. 2017, from https://www.denso-am.eu/media/corporate-news/2017/august-2017-newsletter-compressor-oil-and-refrigerant-mixing-old-and-new/

Dewan, A., Mahanta, P., Raju, K. S., & Kumar, P. S. (2004). Review of passive heat transfer augmentation techniques. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 218*(7), 509-527.

Diani, A., Campanale, M., Cavallini, A., & Rossetto, L. (2018). Low GWP refrigerants condensation inside a 2.4 mm ID microfin tube. *International Journal of Refrigeration, 86*, 312-321.

Diani, A., Cavallini, A., & Rossetto, L. (2017). R1234yf condensation inside a 3.4 mm ID horizontal microfin tube. *International Journal of Refrigeration, 75*, 178-189.

Diani, A., Mancin, S., & Rossetto, L. (2015). Flow boiling heat transfer of R1234yf inside a 3.4mm ID microfin tube. *Experimental Thermal and Fluid Science, 66*, 127-136.

Ding, G.-l. (2007). Recent developments in simulation techniques for vapour-compression refrigeration systems. *International Journal of Refrigeration, 30*(7), 1119-1133.

Dow. (2013). Material Safety Data Sheet. *Ucon Refrigerant Lubricant 213*.

Duangthongsuk, W., & Wongwises, S. (2009). Measurement of temperature-dependent thermal conductivity and viscosity of TiO_2-water nanofluids. *Experimental Thermal and Fluid Science, 33*(4), 706-714.

Dutra, T., & Deschamps, C. J. (2015). A simulation approach for hermetic reciprocating compressors including electrical motor modeling. *International Journal of Refrigeration, 59*, 168-181.

Einstein, A. (1906). A new determination of molecular dimensions. *Ann. Phys, 19*(2), 289-306.

Einstein, A. (1956). *Investigations on the Theory of the Brownian Movement*: Courier Corporation.

Elbel, S., & Lawrence, N. (2016). Review of recent developments in advanced ejector technology. *International Journal of Refrigeration, 62,* 1-18.

Farahmandjou, M., Sebt, S., Parhizgar, S., Aberomand, P., & Akhavan, M. (2009). Stability investigation of colloidal FePt nanoparticle systems by spectrophotometer analysis. *Chinese Physics Letters, 26*(2), 027501.

Fedele, L., Colla, L., Scattolini, M., Bellomare, F., & Bobbo, S. (2014). *Nanofluids application as nanolubricants in heat pumps systems.* Paper presented at the International Refrigeration and Air Conditioning Conference, Purdue.

Fu, L., Wang, R., Cong, W., Li, Q., & Wu, Y. (2008). Experiment study on performance of refrigerator using nano-particle additive. *Hsi-An Chiao Tung Ta Hsueh/Journal of Xi'an Jiaotong University, 42*(7), 852-854.

Giacomin, A. J., & Dealy, J. M. (1993). Large-amplitude oscillatory shear. In *Techniques in rheological measurement* (pp. 99-121). Springer, Dordrecht.

Garg, P., Alvarado, J. L., Marsh, C., Carlson, T. A., Kessler, D. A., & Annamalai, K. (2009). An experimental study on the effect of ultrasonication on viscosity and heat transfer performance of multi-wall carbon nanotube-based aqueous nanofluids. *International Journal of Heat and Mass Transfer, 52*(21), 5090-5101.

Ghadimi, A., Saidur, R., & Metselaar, H. (2011a). A review of nanofluid stability properties and characterization in stationary conditions. *International Journal of Heat and Mass Transfer, 54*(17), 4051-4068.

Gordon, B., Liu, S., & Asada, H. H. (1999). *Dynamic modeling of multiple-zone vapor compression cycles using variable order representations.* Paper presented at the American Control Conference, 1999. Proceedings of the 1999.

Grando, F., Priest, M., & Prata, A. (2005). Lubrication in refrigeration systems: performance of journal bearings lubricated with oil and refrigerant mixtures. *Tribology and Interface Engineering Series, 48*, 481-491.

Grönnerud, R. (1972). Investigation of liquid hold-up, flow-resistance and heat transfer in circulation type evaporators, part IV: two-phase flow resistance in boiling refrigerants. *Bull. De l'Inst. Du Froid, Annexe, 1*.

Gungor, K. E., & Winterton, R. H. S. (1986). A general correlation for flow boiling in tubes and annuli. *International Journal of Heat and Mass Transfer, 29*(3), 351-358.

Gustafsson, T., & Johansson, A. (2015). Comparison between battery electric vehicles and internal combustion engine vehicles fueled by electrofuels: Chalmers University of Technology-Gothenburg, Sweden.

Hamid, K. A., Azmi, W. H., Nabil, M. F., & Mamat, R. (2018a). Experimental investigation of nanoparticle mixture ratios on TiO2–SiO2 nanofluids heat transfer performance under turbulent flow. *International Journal of Heat and Mass Transfer, 118,* 617-627.

Hamid, K. A., Azmi, W. H., Nabil, M. F., Mamat, R., & Sharma, K. V. (2018b). Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO_2-SiO_2 nanofluids. *International Journal of Heat and Mass Transfer, 116*, 1143-1152.

Hamilton, R. L., & Crosser, O. (1962a). Thermal conductivity of heterogeneous two-component systems. *Industrial & Engineering chemistry fundamentals, 1*(3), 187-191.

Hemmat Esfe, M., Abbasian Arani, A. A., & Esfandeh, S. (2018). Improving engine oil lubrication in light-duty vehicles by using of dispersing MWCNT and ZnO nanoparticles in 5W50 as viscosity index improvers (VII). *Applied Thermal Engineering, 143*, 493-506.

Henderson, K., Park, Y.-G., Liu, L., & Jacobi, A. M. (2010). Flow-boiling heat transfer of R-134a-based nanofluids in a horizontal tube. *International Journal of Heat and Mass Transfer*, *53*(5), 944-951.

Hisham, S. M., Kadirgama, K., & Devarajan Ramasamy, S. R. (2020). Enhancement of Tribological Behaviour and Thermal Properties of Hybrid Nanocellulose/Copper (II) Oxide Nanolubricants.

Huang, J., Wang, X., Long, Q., Wen, X., Zhou, Y., & Li, L. (2009). *Influence of pH on the stability characteristics of nanofluids.* Paper presented at the Photonics and Optoelectronics, 2009. SOPO 2009. Symposium on.

Huang, Y., Khajepour, A., Bagheri, F., & Bahrami, M. (2016). Optimal energy-efficient predictive controllers in automotive air-conditioning/refrigeration systems. *Applied Energy, 184*, 605-618.

Huber, M. L., Laesecke, A., & Perkins, R. A. (2003). Model for the viscosity and thermal conductivity of refrigerants, including a new correlation for the viscosity of R134a. *Industrial & Engineering Chemistry Research, 42*(13), 3163-3178.

Hwang, Y.-j., Lee, J., Lee, C., Jung, Y., Cheong, S., Lee, C., Ku, B., & Jang, S. (2007). Stability and thermal conductivity characteristics of nanofluids. *Thermochimica Acta, 455*(1), 70-74.

Hwang, Y., Lee, J.-K., Lee, J.-K., Jeong, Y.-M., Cheong, S.-i., Ahn, Y.-C., & Kim, S. H. (2008). Production and dispersion stability of nanoparticles in nanofluids. *Powder Technology, 186*(2), 145-153.

Illán-Gómez, F., & García-Cascales, J. R. (2019). Experimental comparison of an air-to-water refrigeration system working with R134a and R1234yf. *International Journal of Refrigeration, 97,* 124-131.

Illán-Gómez, F., López-Belchí, A., García-Cascales, J., & Vera-García, F. (2015). Experimental two-phase heat transfer coefficient and frictional pressure drop inside mini-channels during condensation with R1234yf and R134a. *International Journal of Refrigeration, 51*, 12-23.

Ilyas, S. U., Pendyala, R., & Marneni, N. (2017). Stability of Nanofluids. In V. S. Korada & N. Hisham B Hamid (Eds.), *Engineering Applications of Nanotechnology: From Energy to Drug Delivery* (pp. 1-31). Cham: Springer International Publishing.

Janković, Z., Sieres Atienza, J., & Martínez Suárez, J. A. (2015). Thermodynamic and heat transfer analyses for R1234yf and R1234ze(E) as drop-in replacements for R134a in a small power refrigerating system. *Applied Thermal Engineering, 80*, 42-54.

Jarall, S. (2012). Study of refrigeration system with HFO-1234yf as a working fluid. *International Journal of Refrigeration, 35*(6), 1668-1677.

Jia, T., Wang, R., & Xu, R. (2014). Performance of $MoFe_2O_4$-$NiFe_2O_4$/Fullerene-added nano-oil applied in the domestic refrigerator compressors. *International Journal of Refrigeration, 45*, 120-127.

John, T., & Krishnakumar, T. S. (2013). Experimental Studies Of Thermal Conductivity, Viscosity And Stability Of Ethylene Glycol Nanofluids. *International Conference on Energy and Environment, 2013 (ICEE 2013)*(2(1)).

Jwo, C. S., Jeng, L. Y., Teng, T. P., & Chang, H. (2009). Effects of nanolubricants on performance of hydrocarbon refrigerant system. *Journal of Vacuum Science and Technology B: Nanotechnology and Microelectronics, 27*(3), 1473-1477.

Kedzierski, M. A. (2012). R134a/Al_2O_3 nanolubricants mixture pool boiling on a rectangular finned surface. *Journal of Heat Transfer, 134*(12), 1-8.

Kedzierski, M. A. (2013). Nanolubricants to Improve Chiller Performance (U. D. o. Energy, Trans.) (Vol. MAK@NIST.GOV 301 975 5282). USA: US Department of Energy: Energy Efficiency and Renewable Energy.

Kedzierski, M. A., & Gong, M. (2007). *Effect of CuO nanolubricants on R134a pool boiling heat transfer with extensive measurement and analysis details*. USA: US Department of Commerce, National Institute of Standards and Technology.

Keniar, K., & Garimella, S. (2020). A Critical Review of Analytical and Numerical Models of Condensation in Microchannels. *International Journal of Refrigeration*.

Kim, S. H., Choi, S. R., & Kim, D. (2007). Thermal conductivity of metal-oxide nanofluids: particle size dependence and effect of laser irradiation. *Journal of Heat Transfer, 129*(3), 298-307.

Kim, S. J., McKrell, T., Buongiorno, J., & Hu, L.-w. (2010). Subcooled flow boiling heat transfer of dilute alumina, zinc oxide, and diamond nanofluids at atmospheric pressure. *Nuclear Engineering and Design, 240*(5), 1186-1194.

Koban, M. (2009). HFO-1234yf low GWP refrigerant LCCP analysis. *SAE Technical Paper, 2009*, 1-5.

Kole, M., & Dey, T. K. (2011). Effect of aggregation on the viscosity of copper oxide–gear oil nanofluids. *International Journal of Thermal Sciences, 50*(9), 1741-1747.

Krishna Sabareesh, R., Gobinath, N., Sajith, V., Das, S., & Sobhan, C. B. (2012a). Application of TiO_2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems - An experimental investigation. *International Journal of Refrigeration, 35*(7), 1989-1996.

Kumar, D. D., & Arasu, A. V. (2018). A comprehensive review of preparation, characterization, properties and stability of hybrid nanofluids. *Renewable and Sustainable Energy Reviews, 81*, 1669-1689.

Kumar, D. S., & Elansezhian, R. D. (2012). Experimental study on Al_2O_3-R134a nanorefrigerant in refrigeration system. *International Journal of Modern Engineering Research, 2*(5), 3927-3929.

Kumar, S. (2016). *Reciprocating Compressor Performance with Nanorefrigerant in a Vapour Compression System.* (PhD Thesis), Thapar University, Patiala.

Lai, N. A., Vrabec, J., Raabe, G., Fischer, J., & Wendland, M. (2011). Description of HFO-1234yf with BACKONE equation of state. *Fluid Phase Equilibria, 305*(2), 204-211.

Lamb, R. A. (2016). *Refrigerant Choices for The Future–Small Industrial Refrigeration Applications*. UK.

Lambert, J. H., & DiLaura, D. L. (2001). *Photometry, or, on the measure and gradations of light, colors, and shade: translation from the Latin of photometria, sive, de mensura et gradibus luminis, colorum et umbrae*: Illuminating Engineering Society of North America.

Lavrenchenko, G., Ruvinskij, G. Y., Iljushenko, S., & Kanaev, V. (1992). Thermophysical properties of refrigerant R134a. *International Journal of Refrigeration, 15*(6), 386-392.

Lawrence, N., & Elbel, S. (2014). Experimental investigation of a two-phase ejector cycle suitable for use with low-pressure refrigerants R134a and R1234yf. *International Journal of Refrigeration, 38*, 310-322.

Lee, K., Hwang, Y., Cheong, S., Kwon, L., Kim, S., & Lee, J. (2009). Performance evaluation of nano-lubricants of fullerene nanoparticles in refrigeration mineral oil. *Current Applied Physics, 9*(2, Supplement), e128-e131.

Lee, S., Choi, U. S., Li, S., & Eastman, J. A. (1999). Measuring thermal conductivity of fluids containing oxide nanoparticles. *Journal of Heat Transfer, 121*(2), 280-289.

Lee, Y., & Jung, D. (2012). A brief performance comparison of R1234yf and R134a in a bench tester for automobile applications. *Applied Thermal Engineering, 35*(1), 240-242.

Li, B. (2009). *Dynamic modeling and control of vapor compression cycle systems with shut-down and start-up operations.* University of Illinois at Urbana-Champaign.

Li, B., & Alleyne, A. G. (2010). A dynamic model of a vapor compression cycle with shut-down and start-up operations. *International Journal of Refrigeration, 33*(3), 538-552.

Li, G., Eisele, M., Lee, H., Hwang, Y., & Radermacher, R. (2014a). Experimental investigation of energy and exergy performance of secondary loop automotive air-conditioning systems using low-GWP (global warming potential) refrigerants. *Energy, 68*(Supplement C), 819-831.

Li, H., Cao, F., Bu, X., Wang, L., & Wang, X. (2014b). Performance characteristics of R1234yf ejector-expansion refrigeration cycle. *Applied Energy, 121*, 96-103.

Li, H., Yang, W., Yu, Z., & Zhao, L. (2015). The performance of a heat pump using nanofluid (R22+ TiO_2) as the working fluid–an experimental study. *Energy Procedia, 75*, 1838-1843.

Li, X., Zhu, D., & Wang, X. (2007). Evaluation on dispersion behavior of the aqueous copper nano-suspensions. *Journal of Colloid and Interface Science, 310*(2), 456-463.

Li, Y., Tung, S., Schneider, E., & Xi, S. (2009). A review on development of nanofluid preparation and characterization. *Powder Technology, 196*(2), 89-101.

Li, Z., Liang, K., & Jiang, H. (2019). Experimental study of R1234yf as a drop-in replacement for R134a in an oil-free refrigeration system. *Applied Thermal Engineering, 153*, 646-654.

Lin, L., Peng, H., Chang, Z., & Ding, G. (2017). Experimental research on degradation of nanolubricants–refrigerant mixture during continuous alternation processes of condensation and evaporation. *International Journal of Refrigeration, 76*, 97-108.

Lin, L., Peng, H., & Ding, G. (2016). Experimental research on particle aggregation behavior in nanorefrigerant–oil mixture. *Applied Thermal Engineering, 98*, 944-953.

Lin, X., Lee, H., Hwang, Y., & Radermacher, R. (2015). A review of recent development in variable refrigerant flow systems. *Science and Technology for the Built Environment, 21*(7), 917-933.

Liu, G., Li, X., Lu, N., & Fan, R. (2005). Enhancing AW/EP property of lubricant oil by adding nano Al/Sn particles. *Tribology Letters, 18*(1), 85-90.

Liu, M. S., Lin, M. C. C., Tsai, C. Y., & Wang, C. C. (2006). Enhancement of thermal conductivity with Cu for nanofluids using chemical reduction method. *International Journal of Heat and Mass Transfer, 49*(17), 3028-3033.

Longo, G. A., Mancin, S., Righetti, G., & Zilio, C. (2019). R1234yf and R1234ze (E) as environmentally friendly replacements of R134a: Assessing flow boiling on an experimental basis. *International Journal of Refrigeration, 108*, 336-346.

Mahbubul, I. M., Saidur, R., & Amalina, M. A. (2013a). Influence of particle concentration and temperature on thermal conductivity and viscosity of Al2O3/R141b nanorefrigerant. *International Communications in Heat and Mass Transfer, 43*(Supplement C), 100-104.

Mahmoud, M., & Karayiannis, T. (2012). *A statistical correlation for flow boiling heat transfer in micro tubes.* Paper presented at the Proceedings of the 3rd European Conference on Microfluidics-Microfluidics.

Maïga, S. E. B., Nguyen, C. T., Galanis, N., & Roy, G. (2004). Heat transfer behaviours of nanofluids in a uniformly heated tube. *Superlattices and Microstructures, 35*(3), 543-557.

Manna, I. (2009). Synthesis, Characterization and Application of Nanofluid— An Overview. *Journal of the Indian Institute of Science, 89*(1).

Manoj Babu, A., Nallusamy, S., & Rajan, K. (2016). experimental analysis on vapour compression refrigeration system using nanolubricants with HFC-134a refrigerant. *Nano Hybrids, 9*, 33-43.

MathWorks. (2015a). Two Phase Flow model: Pipe (2P). from https://www.mathworks.com/help/physmod/simscape/ref/pipe2p.html

MathWorks. (2015b). Two Phase Flow model: Variable Local Restriction from https://www.mathworks.com/help/physmod/simscape/ref/variablelocalrestriction2p.html

Maxwell, J. C. (1904). *A Treatise on Electricity and Magnetism* (2nd ed.). Cambridge, U.K.: Oxford University Press.

Mendoza-Miranda, J. M., Ramírez-Minguela, J. J., Muñoz-Carpio, V. D., & Navarro-Esbrí, J. (2015). Development and validation of a micro-fin tubes evaporator model using R134a and R1234yf as working fluids. *International Journal of Refrigeration, 50,* 32-43.

Meng, X., Qiu, G., Wu, J., & Abdulagatov, I. M. (2013). Viscosity measurements for 2,3,3,3-tetrafluoroprop-1-ene (R1234yf) and trans-1,3,3,3-tetrafluoropropene (R1234ze(E)). *The Journal of Chemical Thermodynamics, 63*, 24-30.

Meng, Z., Zhang, H., Lei, M., Qin, Y., & Qiu, J. (2018). Performance of low GWP R1234yf/R134a mixture asa replacement for R134a in automotive air conditioning systems. *International Journal of Heat and Mass Transfer, 116*, 362-370.

Mezger, T. G. (2006). The rheology handbook: For users of rotational and oscillatory rheometers. *Vincentz network GmbH & Co. KG, Hannover, Germany*.

Miller, S., & Wendlandt, J. (2010). Real-time simulation of physical systems using Simscape. *MATLAB News and Notes*, 1-13.

Minor, B., & Spatz, M. (2008). HFO-1234yf low GWP refrigerant update.

Mintsa, H. A., Roy, G., Nguyen, C. T., & Doucet, D. (2009). New temperature dependent thermal conductivity data for water-based nanofluids. *International Journal of Thermal Sciences*, *48*(2), 363-371.

Molés, F., Navarro-Esbrí, J., Peris, B., Mota-Babiloni, A., & Barragán-Cervera, Á. (2014). Theoretical energy performance evaluation of different single stage vapour compression refrigeration configurations using R1234yf and R1234ze(E) as working fluids. *International Journal of Refrigeration, 44*, 141-150.

MSDS, DENSO Europe B.V. (2018). MSDS PAG-ND12 *ND-OIL12*

SAFETY DATA SHEET (pp. 11). DENSO Europe B.V.
1382 JL Weesp - Netherlands: DENSO Europe B.V.

Murshed, S. M. S., Leong, K. C., & Yang, C. (2005). Enhanced thermal conductivity of TiO_2—water based nanofluids. *International Journal of Thermal Sciences*, *44*(4), 367-373.

Nabil, M. F., Azmi, W. H., Hamid, K. A., Zawawi, N. N. M., Priyandoko, G., & Mamat, R. (2017). Thermo-physical properties of hybrid nanofluids and hybrid nanolubricants: A comprehensive review on performance. *International Communications in Heat and Mass Transfer, 83*, 30-39.

Nagashima, A. (1990). Viscosity, thermal conductivity, and surface tension of high-temperature melts. *International Journal of Thermophysics, 11*(2), 417-432.

Nair, V., Tailor, P. R., & Parekh, A. D. (2016). Nanorefrigerants: A comprehensive review on its past, present and future. *International Journal of Refrigeration, 67*, 290-307.

Nam, E. K. (2000). Understanding and modeling NOx emissions from air conditioned automobiles: SAE Technical Paper.

Naumann, R. J., & Lehoczky, S. L. (1983). Effect of variable thermal conductivity on isotherms in Bridgman growth. *Journal of Crystal Growth, 61*(3), 707-710.

Navarro-Esbrí, J., Cabello, R., & Torrella, E. (2005). Experimental evaluation of the internal heat exchanger influence on a vapour compression plant energy efficiency working with R22, R134a and R407C. *Energy, 30*(5), 621-636.

Navarro-Esbrí, J., Molés, F., & Barragán-Cervera, Á. (2013). Experimental analysis of the internal heat exchanger influence on a vapour compression system performance working with R1234yf as a drop-in replacement for R134a. *Applied Thermal Engineering, 59*(1-2), 153-161.

Navarro-Esbrí, J., Molés, F., Peris, B., Barragán-Cervera, Á., Mendoza-Miranda, J. M., Mota-Babiloni, A., & Belman, J. M. (2014). Shell-and-tube evaporator model performance with different two-phase flow heat transfer correlations. Experimental analysis using R134a and R1234yf. *Applied Thermal Engineering, 62*(1), 80-89.

Ohunakin, O. S., Adelekan, D. S., Babarinde, T. O., Leramo, R. O., Abam, F. I., & Diarra, C. D. (2017a). Experimental investigation of TiO2-, SiO2- and Al2O3-lubricants for a domestic refrigerator system using LPG as working fluid. *Applied Thermal Engineering, 127*, 1469-1477.

Ohunakin, O. S., Adelekan, D. S., Babarinde, T. O., Leramo, R. O., Abam, F. I., & Diarra, C. D. (2017b). Experimental investigation of TiO2-, SiO2-and Al2O3-lubricants for a domestic refrigerator system using LPG as working fluid. *Applied Thermal Engineering, 127*, 1469-1477.

Olson, J., & Lambert, S. (2012). Hot surface ignition and fire propagation characteristics of R134a and R1234yf refrigerants. *SAE International Journal of Materials and Manufacturing, 5*, 449-460.

Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer an International Journal, 11*(2), 151-170.

Park, K.-J., & Jung, D. (2010). Nucleate boiling heat transfer coefficients of R1234yf on plain and low fin surfaces. *International Journal of Refrigeration, 33*(3), 553-557.

Park, K.-J., Kang, D. G., & Jung, D. (2011). Condensation heat transfer coefficients of R1234yf on plain, low fin, and Turbo-C tubes. *International Journal of Refrigeration*, *34*(1), 317-321.

Park, K.-J., Lee, Y.-H., Choe, D.-S., & Jung, D.-S. (2010). Performance of R1234yf and R1234yf/R134a Mixture under Mobile Air-conditioner Operating Conditions. *Korean Journal of Air-Conditioning and Refrigeration Engineering, 22*(12), 837-844.

Park, K. J., & Jung, D. (2007). Boiling heat transfer enhancement with carbon nanotubes for refrigerants used in building air-conditioning. *Energy and Buildings, 39*(9), 1061-1064.

Pastoriza-Gallego, M. J., Casanova, C., Legido, J. L., & Piñeiro, M. M. (2011). CuO in water nanofluid: Influence of particle size and polydispersity on volumetric behaviour and viscosity. *Fluid Phase Equilibria*, *300*(1), 188-196.

Paul, W. (2013). A/C industry faces challenges from Daimler R-1234yf issue, explores other options. (11870). http://articles.sae.org/11870/

Peidao, O. Z. X. B. D., & Yulin, M. S. Q. (2000). Progress in application and research of nano-lubricating materials. *Materials Review, 8*, 1-9.

Pottker, G., & Hrnjak, P. (2015). Experimental investigation of the effect of condenser subcooling in R134a and R1234yf air-conditioning systems with and without internal heat exchanger. *International Journal of Refrigeration, 50*, 104-113.

Powell, R., Ho, C. Y., & Liley, P. E. (1966). *Thermal conductivity of selected materials* (Vol. 8): US Department of Commerce, National Bureau of Standards Washington, DC.

Pownraj, C., & Valan Arasu, A. (2021). Effect of dispersing single and hybrid nanoparticles on tribological, thermo-physical, and stability characteristics of lubricants: a review. *Journal of Thermal Analysis and Calorimetry*, *143*, 1773-1809.

Prabakaran, R., & Mohan Lal, D. (2018). A novel exergy based charge optimisation for a mobile air conditioning system. *Journal of Thermal Analysis and Calorimetry, 132*(2), 1241-1252.

Putnam, S. A., Cahill, D. G., Braun, P. V., Ge, Z., & Shimmin, R. G. (2006). Thermal conductivity of nanoparticle suspensions. *Journal of Applied Physics, 99*(8), 084308.

Qi, Z. (2013). Experimental study on evaporator performance in mobile air conditioning system using HFO-1234yf as working fluid. *Applied Thermal Engineering, 53*(1), 124-130.

Qi, Z. (2015). Performance improvement potentials of R1234yf mobile air conditioning system. *International Journal of Refrigeration*, *58*, 35-40.

Rao, Y. (2010). Nanofluids: Stability, phase diagram, rheology and applications. *Particuology, 8*(6), 549-555.

Ratts, E. B., & Brown, J. S. (2000). An experimental analysis of cycling in an automotive air conditioning system. *Applied Thermal Engineering*, *20*(11), 1039-1058.

Redhwan, A. A. M. (2018). *Performance analysis of aluminium oxide/polyalkylene glycol nanolubricants in automotive air conditioning system.* (Doctor of Philosophy), Universiti Malaysia Pahang, Faculty of Mechanical Engineering, 26600 Pekan, Pahang.

Redhwan, A. A. M., Azmi, W. H., Sharif, M. Z., & Hagos, F. Y. (2016a). Development of nanolubricants automotive air conditioning (AAC) test rig. *MATEC Web of Conferences*, *90*(01050), 1-8.

Redhwan, A. A. M., Azmi, W. H., Sharif, M. Z., & Mamat, R. (2016b). Development of nanorefrigerants for various types of refrigerant based: A comprehensive review on performance. *International Communications in Heat and Mass Transfer, 76*, 285-293.

Redhwan, A. A. M., Azmi, W. H., Sharif, M. Z., Mamat, R., Samykano, M., & Najafi, G. (2019). Performance improvement in mobile air conditioning system using Al_2O_3/PAG nanolubricants. *Journal of Thermal Analysis and Calorimetry, 135*(2), 1299-1310.

Redhwan, A. A. M., Azmi, W. H., Sharif, M. Z., & Zawawi, N. N. M. (2017a). Thermal conductivity enhancement of Al2O3 and SiO2 nanolubricants for application in automotive air conditioning (AAC) system. *MATEC Web Conf.*, *90*.

Redhwan, A. A. M., Azmi, W. H., Sharif, M. Z., & Zawawi, N. N. M. (2017b). *Thermal conductivity enhancement of Al_2O_3 and SiO_2 nanolubricants for application in automotive air conditioning (AAC) system.* Paper presented at the MATEC Web of Conferences.

Sabareesh, R. K., Gobinath, N., Sajith, V., Das, S., & Sobhan, C. B. (2012). Application of TiO_2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems–An experimental investigation. *International Journal of Refrigeration, 35*(7), 1989-1996.

SAE. International standard J2765 2008.

SAEJ2765, S. I. S. (2008). SAE J2765 - Procedure for Measuring System COP [Coefficient of Performance] of a Mobile Air Conditioning System on a Test Bench (pp. 20): SAE internationals.

Saidur, R., Leong, K. Y., & Mohammad, H. A. (2011). A review on applications and challenges of nanofluids. *Renewable and Sustainable Energy Reviews, 15*(3), 1646-1668.

Saitoh, S., Dang, C., Nakamura, Y., & Hihara, E. (2011). Boiling heat transfer of HFO-1234yf flowing in a smooth small-diameter horizontal tube. *International Journal of Refrigeration, 34*(8), 1846-1853.

Sánchez, D., Cabello, R., Llopis, R., Arauzo, I., Catalán-Gil, J., & Torrella, E. (2017). Energy performance evaluation of R1234yf, R1234ze(E), R600a, R290 and R152a as low-GWP R134a alternatives. *International Journal of Refrigeration, 74*, 269-282.

Sánchez, D., Patiño, J., Llopis, R., Cabello, R., Torrella, E., & Fuentes, F. V. (2014). New positions for an internal heat exchanger in a CO2 supercritical refrigeration plant. Experimental analysis and energetic evaluation. *Applied Thermal Engineering, 63*(1), 129-139.

Sarkar, J. (2012). Ejector enhanced vapor compression refrigeration and heat pump systems—A review. *Renewable and Sustainable Energy Reviews, 16*(9), 6647-6659.

Senthilkumar, A., Anderson, A., & Praveen, R. (2020). Prospective of nanolubricants and nano refrigerants on energy saving in vapour compression refrigeration system – A review. *Materials Today: Proceedings*.

Shafi, W. K., & Charoo, M. S. (2020). An overall review on the tribological, thermal and rheological properties of nanolubricants. *Tribology - Materials, Surfaces & Interfaces*, 1-35.

Shah, R., Alleyne, A. G., Bullard, C. W., Rasmussen, B. P., & Hrnjak, P. S. (2003). Dynamic modeling and control of single and multi-evaporator subcritical vapor compression systems: Air Conditioning and Refrigeration Center. College of Engineering

Shalkevich, N., Escher, W., Bürgi, T., Michel, B., Si-Ahmed, L., & Poulikakos, D. (2009). On the thermal conductivity of gold nanoparticle colloids. *Langmuir, 26*(2), 663-670.

Shao, S., Shi, W., Li, X., & Yan, Q. (2008). Simulation model for complex refrigeration systems based on two-phase fluid network–Part I: Model development. *International Journal of Refrigeration, 31*(3), 490-499.

Sharma, K., Sarma, P., Azmi, W., Mamat, R., & Kadirgama, K. (2012). Correlations to predict friction and forced convection heat transfer coefficients of water based nanofluids for turbulent flow in a tube. *International Journal of Microscale and Nanoscale Thermal and Fluid Transport Phenomena, 3*(4), 283.

Sidik, N. A. C., Mohammed, H., Alawi, O. A., & Samion, S. (2014). A review on preparation methods and challenges of nanofluids. *International Communications in Heat and Mass Transfer, 54,* 115-125.

Sieres, J., & Santos, J. M. (2018). Experimental analysis of R1234yf as a drop-in replacement for R134a in a small power refrigerating system. *International Journal of Refrigeration, 91*, 230-238.

Soliman, A. M., Taher, S. H., Abdel-Rahman, A. K., & Ookawara, S. (2015). *Performance enhancement of vapor compression cycle using nano materials.* Paper presented at the International Conference on Renewable Energy Research and Applications, Palermo, Italy.

Sonawane, S. S., Khedkar, R. S., & Wasewar, K. L. (2015). Effect of sonication time on enhancement of effective thermal conductivity of nano TiO_2–water, ethylene glycol, and paraffin oil nanofluids and models comparisons. *Journal of Experimental Nanoscience, 10*(4), 310-322.

Spatz, M. (2009). *HFO-1234yf Technology Update–Part II.* Paper presented at the VDA Winter Meeting. Saalfelden, Austria.

Spatz, M., & Minor, B. (2008a). HFO-1234yf-A Low GWP Refrigerant for MAC. In D. a. H. Collaboration (Ed.), *VDA Alternative Refrigerant Meeting 2008*. Saalfelden, Austria.

Spatz, M., & Minor, B. (2008b). *HFO-1234yf low GWP refrigerant: a global sustainable solution for mobile air conditioning.* Paper presented at the SAE 2008 Alternate Refrigerant System Symposium, Scottsdale, Arizona, USA.

Spatz, M., Minor, B., & DuPont, H. (2008). *HFO-1234yf.* Paper presented at the A low GWP refrigerant for MAC, Honeywell/DuPont joint collaboration, VDA Alternative Refrigerant Winter Meeting.

Srinivasan, K., Ng, K. C., Velasco, S., & White, J. A. (2012). A corresponding states treatment of the liquid–vapor saturation line. *The Journal of Chemical Thermodynamics, 44*(1), 97-101.

Stubblefield, M., & Haynes, J. H. (1993). *Heating & Air Conditioning Systems Manual*. Haynes North America, Incorporated.

Subramani, N., & Prakash, M. J. (2011). Experimental studies on a vapour compression system using nanorefrigerants. *International Journal of Engineering, Science and Technology, 3*(9), 95-102.

Sukri, M., Musa, M., Senawi, M., & Nasution, H. (2015). Achieving a better energy-efficient automotive air-conditioning system: a review of potential technologies and strategies for vapor compression refrigeration cycle. *Energy Efficiency, 8*(6), 1201-1229.

Sumeru, K., Nasution, H., & Ani, F. N. (2012). A review on two-phase ejector as an expansion device in vapor compression refrigeration cycle. *Renewable and Sustainable Energy Reviews, 16*(7), 4927-4937.

Sundar, L. S., Farooky, M. H., Sarada, S. N., & Singh, M. (2013). Experimental thermal conductivity of ethylene glycol and water mixture based low volume concentration of Al2O3 and CuO nanofluids. *International Communications in Heat and Mass Transfer, 41*, 41-46.

Sundén, B. (2012). *Introduction to heat transfer*: WIT Press.

Sunqing, Q., Junxiu, D., & Guoxu, C. (1999). A review of ultrafine particles as antiwear additives and friction modifiers in lubricating oils. *Lubrication Science, 11*(3), 217-226.

Tanner, R. I., & Walters, K. (1998). Rheology: an historical perspective. Elsevier.

Takizawa, K. (2008). HFO-1234yf-A Low GWP Refrigerant for MAC. In D. a. H. Collaboration (Ed.), *VDA Alternative Refrigerant Meeting 2008*. Saalfelden, Austria.

Tavman, I., Turgut, A., Chirtoc, M., Hadjov, K., Fudym, O., & Tavman, S. (2010). Experimental study on thermal conductivity and viscosity of water-based nanofluids. *Heat Transfer Research, 41*(3).

Tillner-Roth, R., & Baehr, H. D. (1994). An international standard formulation for the thermodynamic properties of 1, 1, 1, 2-Tetrafluoroethane (HFC-134a) for temperatures from 170 K to 455 K and pressures up to 70 MPa. *Journal of Physical and Chemical Reference Data, 23*(5), 657-729.

Timofeeva, E. V., Gavrilov, A. N., McCloskey, J. M., Tolmachev, Y. V., Sprunt, S., Lopatina, L. M., & Selinger, J. V. (2007). Thermal conductivity and particle agglomeration in alumina nanofluids: experiment and theory. *Physical Review E, 76*(6), 061203.

Totten, G. E., Westbrook, S. R., & Shah, R. J. (2003). *Fuels and lubricants handbook: technology, properties, performance, and testing*.

Turanov, A. N., & Tolmachev, Y. V. (2009). Heat-and mass-transport in aqueous silica nanofluids. *Heat and Mass Transfer, 45*(12), 1583-1588.

Uddin, K., Saha, B. B., Thu, K., & Koyama, S. (2019). Low GWP Refrigerants for Energy Conservation and Environmental Sustainability *Advances in Solar Energy Research* (pp. 485-517): Springer.

Vajjha, R. S., Das, D. K., & Kulkarni, D. P. (2010). Development of new correlations for convective heat transfer and friction factor in turbulent regime for nanofluids. *International Journal of Heat and Mass Transfer, 53*(21), 4607-4618.

Viswanath, D. S., Ghosh, T. K., Prasad, D. H., Dutt, N. V., & Rani, K. Y. (2007). *Viscosity of liquids: theory, estimation, experiment, and data*: Springer Science & Business Media.

Wang, C.-C. (2014). System performance of R-1234yf refrigerant in air-conditioning and heat pump system–An overview of current status. *Applied Thermal Engineering, 73*(2), 1412-1420.

Wang, K. J., Ding, G. L., & Jiang, W. T. (2005). *Development of nanorefrigerant and its rudiment property.* Paper presented at the 8th International Symposium on Fluid Control, Measurement and Visualization, Chengdu, China.

Wang, Q., Gao, M., & Zhang, S. (2000). Nanofriction properties of molecular deposition films. *Science in China Series B: Chemistry, 43*(2), 137-142.

Wang, R., Wu, Q., & Wu, Y. (2010). Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants. *Energy and Buildings, 42*(11), 2111-2117.

Wang, R. X., Hao, B., & Xie, G. Z. (2003). *A refrigerating system using HFC134a and mineral lubricant appended with n-TiO_2 as working fluids.* Paper presented at the Proceedings of the 4th International Symposium on HAVC, Beijing, China.

Wang, X., Xu, X., & Choi, S. U. S. (1999a). Thermal conductivity of nanoparticle-fluid mixture. *Journal of Thermophysics and Heat Transfer, 13*(4), 474-480.

Wei, X., & Wang, L. (2010). Synthesis and thermal conductivity of microfluidic copper nanofluids. *Particuology, 8*(3), 262-271.

Witharana, S., Palabiyik, I., Musina, Z., & Ding, Y. (2013). Stability of glycol nanofluids—the theory and experiment. *Powder Technology, 239*, 72-77.

Wong, V. W., & Tung, S. C. (2016). Overview of automotive engine friction and reduction trends–Effects of surface, material, and lubricant-additive technologies. *Friction, 4*(1), 1-28.

Xing, M., Wang, R., & Yu, J. (2014). Application of fullerene C60 nano-oil for performance enhancement of domestic refrigerator compressors. *International Journal of Refrigeration, 40*, 398-403.

Xing, M., Yu, J., & Wang, R. (2015). Experimental study on the thermal conductivity enhancement of water based nanofluids using different types of carbon nanotubes. *International Journal of Heat and Mass Transfer*, *88*, 609-616.

Yang, L., Jiang, W., Ji, W., Mahian, O., Bazri, S., Sadri, R., Badruddin, I. A., & Wongwises, S. (2020). A review of heating/cooling processes using nanomaterials suspended in refrigerants and lubricants. *International Journal of Heat and Mass Transfer, 153*, 119611.

Yang, L., Xu, J., Du, K., & Zhang, X. (2017). Recent developments on viscosity and thermal conductivity of nanofluids. *Powder Technology, 317*, 348-369.

Youbi-Idrissi, M., Bonjour, J., Terrier, M. F., Marvillet, C., & Meunier, F. (2004). Oil presence in an evaporator: experimental validation of a refrigerant/oil mixture enthalpy calculation model. *International Journal of Refrigeration, 27*(3), 215-224.

Yu, W., & Choi, S. (2003). The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model. *Journal of nanoparticle research, 5*(1-2), 167-171.

Yu, W., & Xie, H. (2012). A review on nanofluids: preparation, stability mechanisms, and applications. *Journal of Nanomaterials, 2012*, 1.

Yusof, T. M., Arshad, A. M., Suziyana, M. D., Chui, L. G., & Basrawi, M. F. (2015). Experimental study of a domestic refrigerator with POE-Al_2O_3 nanolubricants. *International Journal of Automotive and Mechanical Engineering, 11*, 2243-2252.

Yusri, I. M., Mamat, R., Azmi, W. H., Najafi, G., Sidik, N. A. C., & Awad, O. I. (2016). Experimental investigation of combustion, emissions and thermal balance of secondary butyl alcohol-gasoline blends in a spark ignition engine. *Energy Conversion and Management, 123*, 1-14.

Zawawi, N. N. M., Azmi, W. H., Redhwan, A. A. M., & Sharif, M. Z. (2017). *Coefficient of friction and wear rate effects of different composite nanolubricants concentrations on Aluminium 2024 plate.* Paper presented at the IOP Conference Series: Materials Science and Engineering.

Zawawi, N. N. M., Azmi, W. H., Redhwan, A. A. M., Sharif, M. Z., & Samykano, M. (2018). Experimental investigation on thermo-physical properties of metal oxide composite nanolubricants. *International Journal of Refrigeration, 89*, 11-21.

Zawawi, N. N. M., Azmi, W. H., Sharif, M. Z., & Najafi, G. (2019). Experimental investigation on stability and thermo-physical properties of Al_2O_3–SiO_2/PAG nanolubricants with different nanoparticle ratios. *Journal of Thermal Analysis and Calorimetry, 135*(2), 1243-1255.

Zhang, F. Z., Jiang, P. X., Lin, Y. S., & Zhang, Y. W. (2011). Efficiencies of subcritical and transcritical CO2 inverse cycles with and without an internal heat exchanger. *Applied Thermal Engineering*, *31*(4), 432-438.

Zhang, J., Desideri, A., Kærn, M. R., Ommen, T. S., Wronski, J., & Haglind, F. (2017). Flow boiling heat transfer and pressure drop characteristics of R134a, R1234yf and R1234ze in a plate heat exchanger for organic Rankine cycle units. *International Journal of Heat and Mass Transfer, 108*, 1787-1801.

Zhang, Q., Li, S. E., & Deng, K. (2016). *Automotive air conditioning: optimization, control and diagnosis*: Springer.

Zhang, Z.-y., Ma, Y.-t., Wang, H.-l., & Li, M.-x. (2013). Theoretical evaluation on effect of internal heat exchanger in ejector expansion transcritical CO2 refrigeration cycle. *Applied Thermal Engineering, 50*(1), 932-938.