International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Exergy and sustainability investigation of waste heat recovery vapor compression refrigeration system with silver Nano fluid

Kapil Chopra[1], R.S Mishra[2]

[1]*Assistant Professor, Mechanical Engineering Department, Shri Mata Vaishno Devi University, Katra (J&K) India*
[2]*Professor, Department of Mechanical, Production & Industrial Engineering, Delhi Technological University, Delhi, India*

Abstract

In this paper influence of cooling base fluid mass flow rate (500-2000 kg.h^{-1}) with water and silver Nano fluid as cooling base fluid on performance parameters were experimentally evaluated. It was observed that cooling effectiveness, sustainability index, heating capacity, exergy efficiency increases while condensing & evaporation pressures and exergy destruction in components of refrigerant circuit decreases with increasing mass flow rate of cooling base fluid. Cooling effectiveness, exergy efficiency, sustainability index, heating capacity of the considered system improved in the range of 11.71-18.25%, 1.9-4.56% ,0.3-0.7% and 26-80% respectively by using 0.05 vol% silver Nano fluid compared to water as cooling based fluid for considerable range of cooling base fluid flow rate. Improvement was recorded using 0.05 vol% silver Nano fluid compared to water for considerable range of cooling base fluid mass flow rate as exergy destruction decreases in the range of 29-30.18%, 65.77-69.61%, 14.31-15.33%, 17-22% in compressor, condenser, evaporator and expansion valve respectively.
Keywords: Waste heat, Exergy, Sustainability, Global warming, Energy-Exergy Analysis, Nano Technology

1. Introduction

The increasing demand of energy leads to global warming and environmental imbalance in the society. In order to satisfy the needs, utilization of energy available at the systems should be in best way. The primary function of system based on vapour compression refrigeration technology is to reject heat at higher temperature and absorb at lower temperature. Heat rejected by condenser generally not utilized for constructive applications instead of this heat is wasted either to the surrounding or to the water circulating from cooling tower. Like milk plant, vapour compression refrigeration system is used for cooling of milk for the purpose of preserving the same for long time and heat rejected by condenser is wasted to water circulating from cooling tower. In same plant large amount heat is also required for heating of milk to kill bacteria. This much amount of heat is taken either from burning of diesel or other non-renewable resources.
It is very important to increase coefficient of performance, exergy efficiency, and sustainability index on the other hand reduction of exergy destruction in the components of vapour compression refrigeration system. Along with above mentioned parameters, it is also important to utilization of energy available at vapour compression refrigeration system. In view of above factors experimental test rig was fabricated which is used for both cooling and heating of water. Cooling is done by evaporator and utilizes the waste heat from condenser is for heating of water. Silver Nano fluid with 0.01% and 0.05% volume concentration ratio used as cooling base fluid for enhancing of heating. The purpose of using of Nano fluid to improve the performance parameters like effectiveness, exergy efficiency, sustainability index and decrease the irreversibility in components of VCR.
The leakage test of developed test rig was done by filling of nitrogen gas. After successful completion of leakage test, test rig has been evacuated by using of vacuum pump. The vacuum was held for 30 hr and after that the correct amount of R22 was charged in refrigerant circuit. After completion of leakage testing and charging of refrigerant, cooling base fluid

Corresponding author: R.S. Mishra
Email Id: hod.mechanical.rsm@dtu.ac.in

pump, cooling secondary fluid pump, chilled water pump and chilled secondary fluid pump was switched on. Chilled water mass flow rate (300 kg/hr) remain constant for considered number of experiments. Thermostat attached with heating coil used to maintain constant inlet temperature (T_7 =26 ºC) of chilled secondary fluid and thermostat of same configuration attached with cooling coil for constant inlet condition (T_{11} =22 ºC) of cooling secondary fluid. Then compressor of refrigerant circuit was switched on. Before collection of experimental data, system was allowed to run until the steady state condition was reached. Experimental data were recorded six times during one hour. Experiments were done with water followed by 0.01 and 0.05 vol% silver Nano fluid as cooling base fluid with same above described procedure. It should be noted that any fluid to be heated or cooled can be used as cooling or chilled secondary fluid. In the present study water is used in both cooling and secondary fluid circuit. The above discussed experimentation was done under constant (T_a=25 ºC) surrounding condition.

2. Literature Review

Elcock [1] found that TiO_2 nanoparticles can be used as additives to enhance the solubility of the mineral oil with the hydro fluorocarbon (HFC) refrigerant. Author also reported that refrigeration systems using a mixture of HFC134a and mineral oil with TiO_2 nanoparticles appear to give better performance by returning more lubricant oil to the compressor. Hindawi [2] carried out an experimental study on boiling heat transfer characteristics of R22 refrigerant with Al_2O_3 nanoparticles and found that the nanoparticles enhanced the refrigerant heat transfer characteristics by reducing bubble sizes. Eastman et al.[3] investigated the pool boiling heat transfer characteristics of R11 refrigerant with TiO_2 nanoparticles and showed that the heat transfer enhancement reached by 20% at a particle loading of 0.01 g/L. Liu et al.[4] investigated the effects of carbon nanotubes (CNTs) on the nucleate boiling heat transfer of R123 and HFC134a refrigerants. Authors reported that CNTs increase the nucleate boiling heat transfer coefficients for these refrigerants. Jiang et al.[5] experimental results showed that the thermal conductivity of carbon nanotubes (CNT) Nano refrigerants are much higher than those of CNT–water Nano fluids or spherical nanoparticle–R113 Nano refrigerants. Authors reported that the smaller the diameter of CNT larger the thermal conductivity enhancement of CNT Nano refrigerant. Hwang et al.[6] suggested that thermal conductivity enhancement of Nano fluids is greatly influenced by thermal conductivity of nanoparticles and base fluid. For instance, thermal conductivity of water based Nano fluid with multiwall carbon nanotubes has noticeably higher thermal conductivity compared to SiO_2 nanoparticles in the same base fluid. Yoo et al. [7] argued that surface to volume ratio of nanoparticles is a dominant factor. Surface to volume ratio is increased with smaller sizes of nanoparticles. Choi et al.[8] reported that 150% thermal conductivity enhancement was observed in poly (a-olefin) oil by addition of multiwall carbon nanotubes (MWCNT) at 1% volume fraction. Yang.[9] reported, a 200% thermal conductivity enhancement for poly (a-olefin) oil containing 0.35% (v/v) MWCNT. It is important to note that this thermal conductivity enhancement was accompanied by a three order of magnitude increase in viscosity. Eastman et al.[10] observed 40% thermal conductivity enhancement for ethylene glycol with 0.3% (v/v) copper nanoparticles (10 nm diameter), although the authors also added that about 1% (v/v) thioglycolic acid helpful for dispersion of nanoparticles in base fluid. The addition of this dispersant yielded a greater thermal conductivity than the same concentration of nanoparticles in the ethylene glycol without the dispersant.

Author also reported that refrigeration systems using a mixture of HFC134a and mineral oil with TiO_2 nanoparticles appear to give better performance by returning more lubricant oil to the compressor. Hindawi [2] carried out an experimental study on boiling heat transfer characteristics of R22 refrigerant with Al_2O_3 nanoparticles and found that the nanoparticles enhanced the refrigerant heat transfer characteristics by reducing bubble sizes. Eastman et al.[3] investigated the pool boiling heat transfer characteristics of R11 refrigerant with TiO_2 nanoparticles and showed that the heat transfer enhancement reached by 20% at a particle loading of 0.01 g/L. Liu et al.[4] investigated the effects of carbon nanotubes (CNTs) on the nucleate boiling heat transfer of R123 and HFC134a refrigerants. Authors reported that CNTs increase the nucleate boiling heat transfer coefficients for these refrigerants. Jiang et al.[5] experimental results showed that the thermal conductivity of carbon nanotubes (CNT) Nano refrigerants are much higher than those of CNT–water Nano fluids or spherical nanoparticle–R113 Nano refrigerants. Authors reported that the smaller the diameter of CNT larger the thermal conductivity enhancement of CNT Nano refrigerant. Hwang et al.[6] suggested that thermal conductivity enhancement of Nano fluids is greatly influenced by thermal conductivity of nanoparticles and base fluid. For instance, thermal conductivity of water based Nano fluid with multiwall carbon nanotubes has noticeably higher thermal conductivity compared to SiO_2 nanoparticles in the same base fluid. Yoo et al. [7] argued that surface to volume ratio of nanoparticles is a dominant factor. Surface to volume ratio is increased with smaller sizes of nanoparticles. Choi et al.[8] reported that 150% thermal conductivity enhancement was observed in poly (a-olefin) oil by addition of multiwall carbon nanotubes (MWCNT) at 1% volume fraction. Yang.[9] reported, a 200% thermal conductivity enhancement for poly (a-olefin) oil containing 0.35% (v/v) MWCNT. It is important to note that this thermal conductivity enhancement was accompanied by a three order of magnitude increase in viscosity. Eastman et al.[10] observed 40% thermal conductivity enhancement for ethylene glycol with 0.3% (v/v) copper nanoparticles (10 nm diameter), although the authors also added that about 1% (v/v) thioglycolic acid helpful for dispersion of nanoparticles in base fluid. The addition of this dispersant yielded a greater thermal conductivity than the same concentration of

nanoparticles in the ethylene glycol without the dispersant. Kang et al.[11] reported , a 75% thermal conductivity enhancement for ethylene glycol with 1.2% (v/v) diamond nanoparticles between 30 and 50 nm diameter. Despite of these remarkable results, some researchers also measured the thermal conductivity of Nano fluids and found no anomalous results. Lee et al.[12] revealed that optimum combination of pH level and surfactant leads to 10.7% thermal conductivity enhancement of 0.1% Cu/H2O Nano fluid. They also concluded that during Nano fluid preparation stage thermal conductivity of Nano fluid is affected by pH level and addition of surfactant. Jiang et al.[13] added that thermal conductivity of Nano fluids also depend on the nanoparticles size and temperature. Wu et al.[14] observed that the pool boiling heat transfer was enhanced at low TiO_2 nanoparticles concentration in R11 but deteriorated under high nanoparticles concentration. Trisaksri and Wongwises [15] investigated TiO_2 in HCFC 141b in a cylindrical copper tube and found that the nucleate pool boiling heat transfer deteriorated with increasing nanoparticle concentrations especially at higher heat fluxes. Hao et al.[16] investigated flow boiling inside a smooth tube at different nanoparticles concentration, mass fluxes, heat fluxes, and inlet vapor qualities in order to analyze the influence of nanoparticles on the heat transfer characteristics of refrigerant-based Nano fluid. Authors observed that the heat transfer coefficient of refrigerant-based Nano fluid in flow boiling is larger than that of pure refrigerant and the maximum enhancement is about 29.7% when observed with a mass fraction of 0–0.5 wt%. Hao et al. [17] studied experimentally the nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nanoparticles. The results indicate that the nucleate pool boiling heat transfer coefficient of R113/VG68 oil mixture with diamond nanoparticles is larger than that of R113/oil mixture by 63.4%.Enhancement in same factor increases with the increase of nanoparticles concentration in the nanoparticles/oil suspension and decreases with the increase of lubricating oil concentration. Wang et al. [18] carried out an experimental study of boiling heat transfer characteristics of R22 with Al_2O_3 nanoparticles and found that nanoparticles enhanced the refrigerant heat transfer characteristics by reduction of bubble sizes that moved quickly near the heat transfer surface. Li et al. [19] investigated the pool boiling heat transfer characteristics of R-11 with TiO_2 nanoparticles and showed that the heat transfer enhancement reached by 20% at a particle loading of 0.01 g/L. Peng et al. investigated the influence of CuO nanoparticles on the heat transfer characteristics of R-113 refrigerant-based Nano fluids and presented a correlation for prediction of heat transfer performance of refrigerant based Nano fluids. Authors reported that the heat transfer coefficient of refrigerant-based Nano fluids is higher than that of pure refrigerant, and the maximum enhancement of heat transfer coefficient found to be about 29.7%. Kumar and Elansezhian [21] experimentally investigated the effect of varying concentration of ZnO nanoparticles on various performance parameters like COP, suction temperature, input power and pressure ratio with 152a as working fluid in vapour compression refrigeration system. They found that 0.5% v ZnO nanoparticles with R152a gives maximum COP of 3.56 and 21% reduction in power input. Pressure ratio decreases with increase in ZnO concentration. Mahbubul et al.[22] measured thermo physical properties, pressure drop and heat transfer performance of Al_2O_3 nanoparticles and R-134a mixture. Thermal conductivity of Al_2O_3/R-134a Nano refrigerant increased with temperature and augmentation of particle concentration. It was also observed that pumping power, viscosity, pressure drop, and heat transfer coefficients of the Nano refrigerants show significant increment with the increase of volume fractions. The frictional pressure drop also shows rapid increment with 3 vol. % particle fraction.

3. Description of experimental test rig and Instrumentation

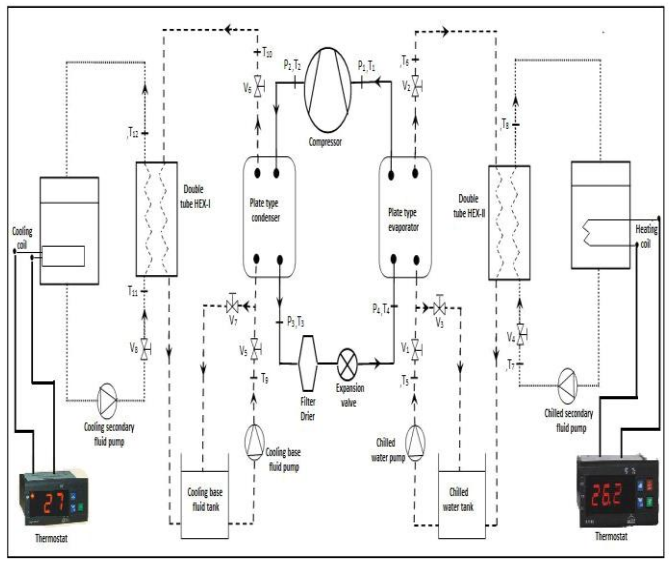

Figure 1: experimental test rig comprising of refrigerant

As shown in Fig.1. experimental test rig comprising of refrigerant, chilled water, chilled secondary fluid, cooling base fluid and cooling secondary fluid circuits. Refrigerant circuit used R22 as working fluid consists of single cylinder hermetically sealed reciprocating compressor, plate type condenser, thermal expansion valve, plate type evaporator and accessories like filter, drier, power meter used for measurement of electricity consumed by compressor and sight glass. Due to high heat transfer coefficient and compact design, plate type heat exchangers.

4. Preparation of Nano fluid

In literature one-step and two-step commonly used for preparation Eastman et al.[10] developed one-step procedure for preparation of Nano fluid. In this method problem of agglomeration was reduced by great extent and preparation and dispersion of solid nanoparticles in base fluid concurrently occurred. This method leads to uniform and stable distribution of nanoparticles in the base fluid. In order to produce Nano fluids in large scale one step procedure is not economical. Zhu et al. developed another method for preparation of Nano fluids called two-step method. In this process nanoparticles directly dispersed in base fluid.

In this paper, two-step method is adopted for preparation of silver nanoparticles and water mixture. Silver nanoparticles of spherical morphology with average particle size 50 nm size and bulk density 0.312 g/cm^3. The TEM image, UV spectrophotometer analysis and raman analysis of silver nanoparticles presented in Fig.2-3 respectively. 0.01 and 0.05% volume concentration ratio silver nanoparticles were measured by digital balance and mixed with water. Probe type ultrasonicator as shown in Fig.4 was used for stable and uniform distribution of nanoparticles in base fluid for 30 min. As shown in Fig 5 shows before ultra-sonication of silver nanoparticles in water. No settlement of nanoparticles and water mixture were observed after 2, 4,6,8,10 and 6 h respectively. As a result 0.01 and 0.05% volume solution has selected for solubility test

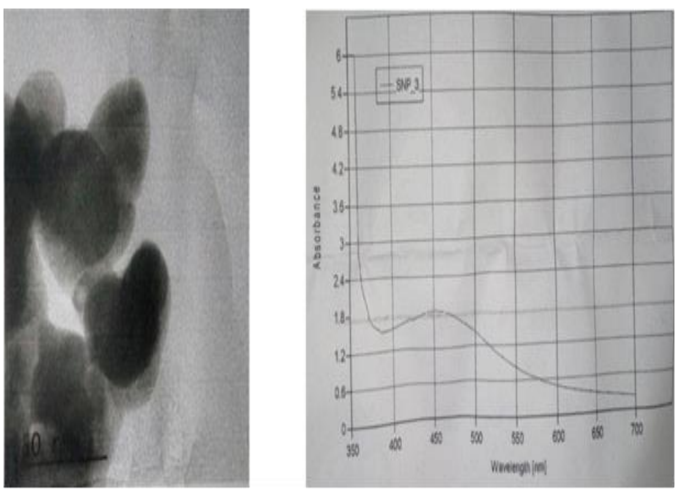

Figure 2: TEM image of silver nanoparticles

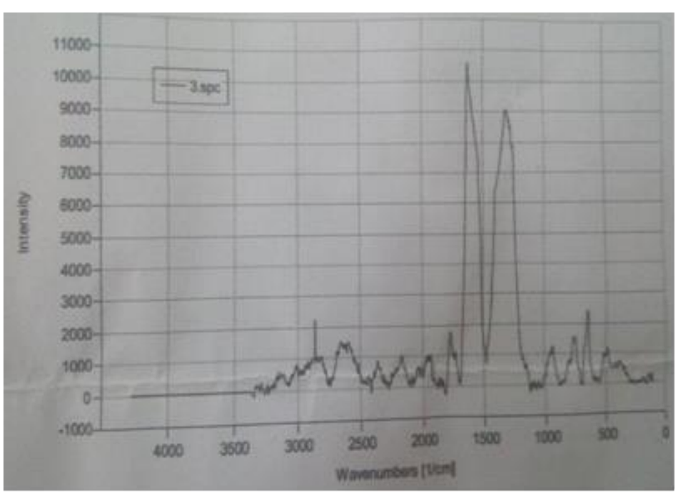

Figure 3: Raman analysis of silver nanoparticles

Figure 4: Probe type sonicator and Digital balance

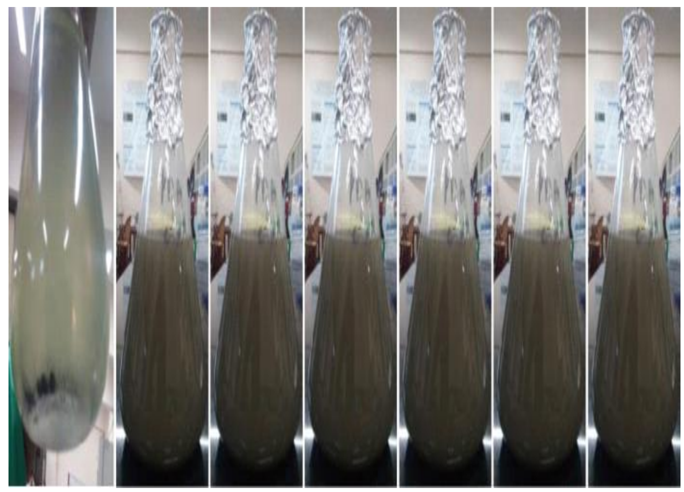

Figure 5: Solubility test

5. Result and Discussion

Fig.6 and Fig.7 presents the effect of variation of mass flow rate of cooling base fluid on working pressures of refrigerant circuit.. It was observed that with increase of mass flow rate of cooling base fluid, operating pressures decreases due to enhancement of heat exchange between refrigerant and cooling base fluid. Both of these figures also revealed that variation of mass flow rate give a more prominent effect on condensing pressure rather than evaporating pressure. Deviation of evaporation and condensation pressures with various working parameters were studied with water, 0.01 and 0.05 vol. % silver Nano fluid as cooling base fluid. As shown in Fig. 6, water and 0.05 vol. % silver Nano fluid give maximum & minimum condensation pressure respectively. Pertaining to evaporation pressure, Fig.7 reveals that water gives highest while 0.05 vol. % silver Nano fluids gives lowest evaporating pressure. The average values of condensation pressure for water, 0.01 and 0.05 vol. % silver Nano fluid as cooling base fluids are 1417.06, 1393.57 and 1230.73 KPa while their evaporation pressures are 196.13, 192.26 and 169.16 KPa respectively over wide range of cooling base fluid mass flow rate (Fig 6 & 7).Mean condensation pressure of water and 0.01 vol. % silver Nano fluid are greater than 0.005 vol% silver Nano fluid by 15.13% and 13.23% respectively. On the other hand average evaporation pressure of water and 0.001 vol. % silver Nano fluids are higher than 0.001 vol. % silver Nano fluid by 15.94% and 13.65% respectively.

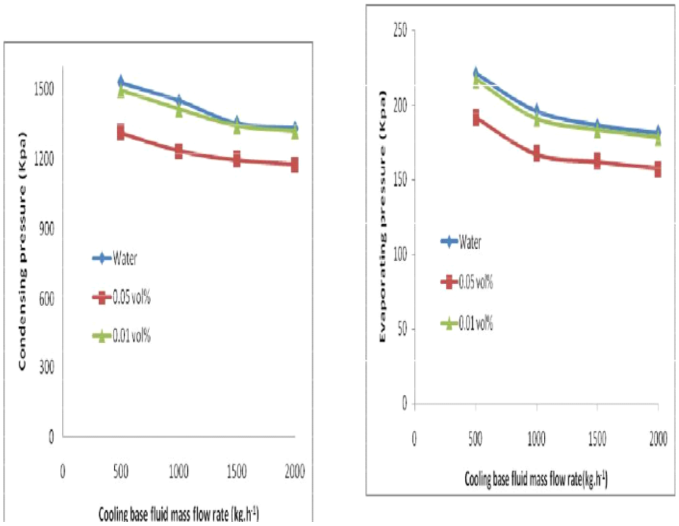

Figure 6: Variation of condensing and evaporator pressures with cooling base fluid mass flow rate (kg.h^{-1})

Variation of cooling effectiveness verses mass flow rate of cooling base fluid is shown in Fig.8. It is evident that higher mass flow rate of cooling base fluid responsible for lower compressor work due to decreasing of compressor to evaporator ratio and increases cooling & heating effectiveness. Increases cooling & heating capacity and decrement in compressor work increases the cooling and heating effectiveness of the system. Average cooling effectiveness of system using 0.05 vol. % silver Nano fluid as cooling base fluid is higher than that of water by 14.98% as cooling base fluid over considered range of mass flow rate of cooling base fluid (fig.8). and Fig.9 show the impact of mass flow rate of cooling base fluid on exergy efficiency and exergy destruction ratio respectively. Since exergy efficiency is the ratio of useful output in term of cooling capacity to the input energy given to the system.

We know that the input energy given in term of compressor work gets lower down with increase of mass flow rate of cooling base fluid. Like compressor work numerator of exergy efficiency also follow the same trend. Combined effect of both discussed terms increase the exergy efficiency.

The behavior of trends is due to fact that exergy destruction ration and exergy efficiency are inversely proportional to each other. Behavior of Sustainability index with change of mass flow rate of cooling base fluid was also analyzed. The sustainability index is the function of exergy efficiency. Sustainability index determines the impact on environmental or surrounding conditions. Lower sustainability index of the system put adverse effect on the environmental conditions.

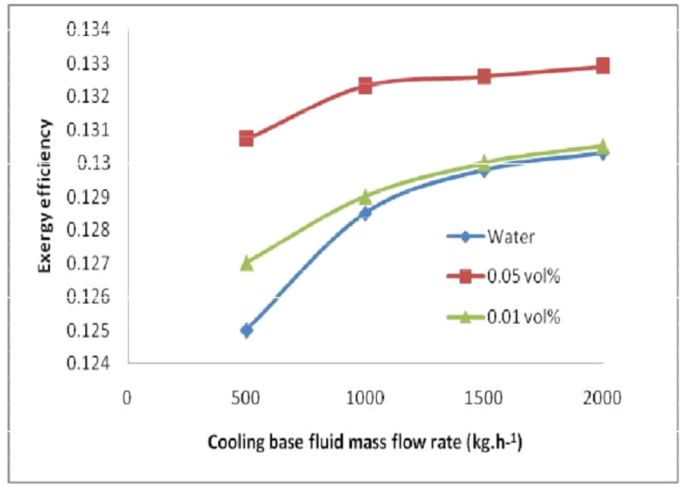

Figure 7: Variation of Exergy efficiency with cooling base fluid mass flow rate (kg.h^{-1})

The Average value of sustainability index of the system using water, 0.01 vol% and 0.05 vol% Nano fluid as cooling base fluid are 1.147, 1.148., and 1.152 respectively. Base fluid. Average specific heat of 0.05 and 0.01 vol% Nano fluid is higher than water; also temperature rise of 0.05 vol% of Nano fluid is much higher than water and 0.01 vol% Nano fluid over entire range of cooling base fluid mass flow rate. This increase in heat transfer termed as heating capacity of condenser, maximum 80% heat capacity higher when 0.05 vol% Base fluid. Average specific heat of 0.05 and 0.01 vol% Nano fluid is higher than water; also temperature rise of 0.05 vol% of Nano fluid is much higher than water and 0.01 vol% Nano fluid over entire range of cooling base fluid mass flow rate. This increase in heat transfer termed as heating capacity of condenser, maximum 80% heat capacity higher when 0.05 vol%. the performance with nano fluid are shown in Fig-7-9 respectively.

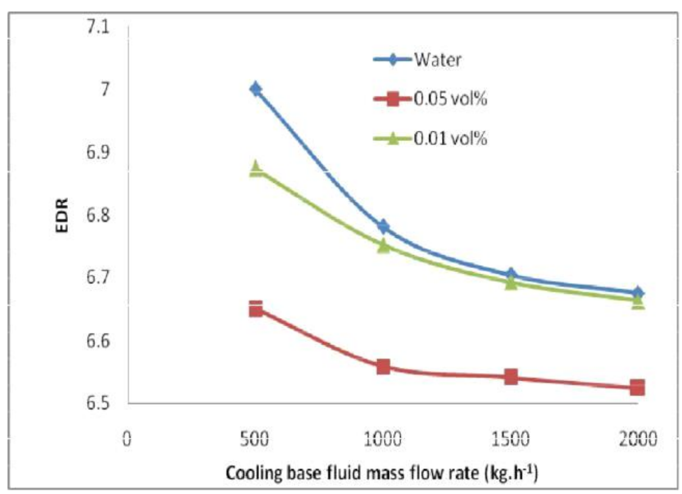

Figure 8: Variation of EDR with cooling base fluid mass flow rate (kg.h^{-1})

The heating capacity is the product of mass flow rate, specific heat and temperature rise of cooling base fluid. By keeping constant mass flow rate of water and discussed percentage of Nano fluid remaining Nano fluids is used instead of water at 2000 Kg/h cooling base fluid mass flow rate. two factors i.e specific heat and temperature difference of cooling base fluid responsible for increase of heat transfer between refrigerant through condenser and cooling two factors i.e specific heat and temperature difference of cooling base fluid responsible for increase of heat transfer between refrigerant through condenser and cooling

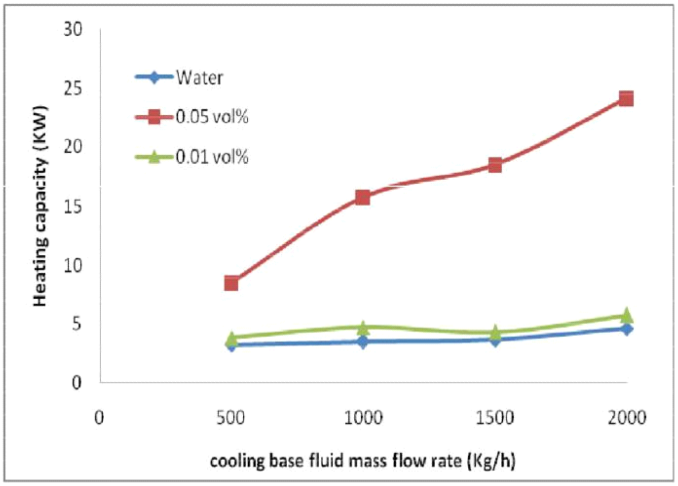

Figure 9: Variation of heating capacity with cooling base fluid mass flow rate (kg.h^{-1})

Table-1(a) : exergy destruction in compressor, condenser, expansion valve & evaporator

Cooling base mass flow rate of water	Ė1-2	Ė2-3	Ė3-4	Ė4-1
(Kg.h^{-1})	(W)	(W)	(W)	(W)
500	918.2	206.2	23.83	99.13
1000	869.6	185.9	22.47	98.44
1500	867.5	169.1	22.28	96.00
2000	837.4	161.4	21.41	95.85

Table-1(b) : exergy destruction in compressor, condenser, expansion valve & evaporator

Cooling base mass flow rate of water 0.01 vol% nano	Ė1-2	Ė2-3	Ė3-4	Ė4-1
(Kg.h^{-1})	(W)	(W)	(W)	(W)
500	856.3	173.4	22.81	97.82
1000	814.4	155.5	21.62	96.73
1500	807.4	142.6	21.52	94.62
2000	781.8	136.19	0.85	94.22

Table-1(c) : exergy destruction in compressor, condenser, expansion valve & evaporator

Cooling base mass flow rate of water 0.05 vol% nano	Ė1-2	Ė2-3	Ė3-4	Ė4-1
(Kg.h^{-1})	(W)	(W)	(W)	(W)
500	708.9	123.4	19.50	86.72
1000	677.8	109.6	18.61	85.35
1500	666.6	101.9	18.61	83.77
2000	648.1	97.36	18.20	83.16

Table-1 illustrate the variation of exergy destruction in compressor, condenser, expansion valve & evaporator with variation in mass flow rate of cooling base fluid. Exergy destruction in component is due to depletion of input energy in particular component. It also gives idea about best and worst component of the system. It was observed that expansion valve and compressor are the best and worst component of the system respectively for entire range of mass flow rate of cooling base fluid. It is clear from Table.1 that average exergy destruction over wide range of mass flow rate of cooling base fluid in compressor, condenser, expansion valve and evaporator is lowest by 29.92, 67.16, 20.11 and 14.8% respectively when 0.05 vol. % silver nanofluid compared to water used as cooling base fluid. Mean exergy destruction in compressor, condenser, capillary tube & evaporator ***is*** 873.18, 180.65, 22.50 and 97.36 W respectively which is highest in case of water used as secondary fluid through evaporator. 7.13, 18.88,3.68 and 1.57 % reduction of exergy destruction in compressor, condenser, expansion valve & evaporator respectively by using of 0.01 vol. silver Nano fluid used as cooling base fluid compared to water.

6. Conclusion

In this paper, various performance parameters of waste heat recovery vapor compression refrigeration system with water, 0.01 and 0.05vol. % silver Nano fluid as cooling base fluid through condenser were experimentally evaluated and compared over considered range of working states.
Based on the experimental investigation, following results are discussed:

(i) Maximum evaporation and condensation pressure produces with when water is used as cooling base fluid. While 0.05 vol. % silver Nano fluid as cooling base fluid generate minimum evaporation and condensation pressure.
(ii) Maximum cooling effectiveness was monitored when 0.05 vol. % silver Nano fluid compared to water used as cooling base fluid. However lesser effect was observed in cooling effectiveness of the system by using 0.05 vol. % silver Nano fluid in comparison with water as cooling base fluid.
(iii) Minimum exergy destruction and exergy ratio produces in components of the system with 0.05 vol. % silver Nano fluid as cooling base fluid.
(iv) Highest sustainability index, heating capacity and exergy efficiency is observed with 0.05 vol. % silver Nano fluid as cooling base fluid.
(v) Insignificant effect on performance parameters was observed with 0.01 vol. % silver Nano fluid as cooling base fluid.

References

[1] Elcock D. Potential, Impacts of nanotechnology on energy transmission applications and needs, Environmental Science Division, Argonne National Laboratory (2007).

[2] Hindawi, Special issue on heat transfer in nanofluids (2009)

[3] Eastman JA, Choi US, Thompson LJ and Lee S, Enhanced thermal conductivity through the development of nanofluids, Mater Res Soc Symp Proc, 457 (1996) 3–11.

[4] Liu MS, Lin MCC, Huang IT and Wang CC, Enhancement of thermal conductivity with CuO for Nanofluids, Chemical Engineering and Technology 29(1) (2006) 72–77.

[5] Jiang W, Ding G and Peng H, Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants, International Journal of Thermal Sciences 48 (2009) 1108–1115

[6] Hwang YJ, Ahn YC, Shin HS, Lee CG, Kim GT and Park HS, Investigation on characteristics of thermal conductivity enhancement of nanofluids, Current Applied Physics 6(6) (2006) 1068–1071.

[7] DH, Hong KS and Yang HS, Study of thermal conductivity of nanofluids for the application of heat transfer fluids, Thermochimica Acta 2007;455(1–2):66–69.

[8] Choi SUS, Zhang ZG, Yu W, Lockwood FE and Grulke EA. , Anomalous thermal conductivity enhancement in nanotube suspensions, Applied Physics Letters 79(14) (2001) 2252–2254.

[9] Yang Y. Carbon nanofluids for lubricant application. University of Kentucky (2006).

[10] Eastman JA, Choi SUS, Li S, Yu W, and Thompson LJ, Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied Physics Letters 78(6) (2001) 718–720.

[11] Kang H.U, Kim S.H and Oh J.M., Estimation of thermal conductivity of nanofluid using experimental effective particle, Experimental Heat Transfer 19(3) (2006) 181–191.

[12] Lee J.H, Hwang K.S, Jang S.P, Lee B.H, Kim J.H and Choi SUS, Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3 nanoparticles. International Journal of Heat and Mass Transfer 51 (2008) 2651–2656.

[13] Jiang W, Ding G and Peng H., Measurement and model on thermal conductivities of

[14] carbon nanotube nanorefrigerants. International Journal of Thermal Sciences 48 (2009) 1108–1115.

[15] Wu X.M, Li P, Li H and Wang W.C, Investigation of pool boiling heat transfer of R11 with TiO_2 nano-particles. Journal of Engineering Thermophysics 29(1) (2008) 124–126.

[16] Trisaksri V and Wongwises S, Nucleate pool boiling heat transfer of TiO_2–R141b nanofluids, International Journal of Heat and Mass Transfer 52 (2009) 1582–1588.

[17] Hao P, Guoliang D, Weiting J, Haitao H and Yifeng G, Heat transfer characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube. International Journal of Refrigeration 32 (2009) 1259–1270.

[18] Hao P, Guoliang D, Haitao H, Weiting J, awei Z and Kaijiang W. Nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nanoparticles. International Journal of refrigeration 33 (2010) 347–358.

[19] Wang K.J, Ding G.L and Jiang WT, Nano-scale thermal transporting and its use in engineering, Proceedings of the 4th symposium on refrigeration and air condition (2006) 66–75.

[20] Li P, Wu XM and Li H, Pool boiling heat transfer experiments of refrigerants with nanoparticles TiO_2, Proceedings of the 12th symposium on engineering thermo physics, (2006) 325–333.

[21] Peng H, Ding G, Jiang W, Hu H and Gao Y, Heat transfer characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube. International Journal of Refrigeration 32 (2009):1259– 1270.

[22] D.Sendil Kumar and R. Elansezhian, ZnO nanorefrigerant in R152a refrigeration system for energy conservation and green environment, J Front Mech Engg (2014) 1-6.

[23] I.M. Mahbubul,S.A. Fadhilah, R. Saidur, K.Y. Leong and M.A. Amalina, Thermophysical properties and heat transfer performance of Al_2O_3/R-134a Nano refrigerants, International Journal of Heat and Mass Transfer 57 (2013) 100–108.