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Thermodynamic analysis of J-T system using blend of hydrocarbons with Al_2O_3 nano lubricant

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ABSTRACT

This paper reviews the possibilities of researches in the field of thermodynamic analysis in various usable sectors where Joule - Thomson refrigeration systems are used. Here, it is found that exergy depends on evaporating temperature, condensing temperature, sub-cooling and compressor pressure. It also depends on environmental temperature. Nowadays, hydrocarbons are considered as refrigerant having low ODP and GWP, and these are considerable in the aspect of exergy analysis. Refrigerants R 290 and R 600a are considered and analyzed with respect to exergy efficiency. Mixture of hydrocarbons R290 and R600a (40/60 by weight) shows better performance with respect to other refrigerants. Among the components of the J-T system, much research showed that major part of exergy losses is occurred in the compressor. Al_2O_3 nanoparticle and POE lubricant cause to reduce the exergy losses in the compressor of the J-T system indirectly.

Key Words: Joule - Thomson refrigeration system, Hydro carbon refrigerants, Exergy analysis, Nano Lubricant

INTRODUCTION

The energy balance is a basic technique of any process investigation. It makes the energy analysis possible, points at the needs to progress the process, is the key to optimization and is the basis to develop the exergy balance. Analysis of the energy balance results would disclose the efficiency of energy utilization in particular parts of the process and allow comparing the efficiency and the process parameters with the currently achievable values in the most modern installations. The modern approach to process analysis uses the exergy analysis, which provides a more realistic view of the process. The exergy analysis is the contemporary thermodynamic method used as an advanced and useful tool for engineering process evaluation (Szargut, 1998). Whereas, the energy analysis is based on the first law of thermodynamics, and the exergy analysis is based on both the first and second laws of thermodynamics. Both analyses utilize also the material balance for the systems considered.

Thermodynamic processes in Joule - Thomson refrigeration systems release large amounts of heat to the environment. Heat transfer between the system and the surrounding environment takes place at a finite temperature difference, which is a major source of irreversibility for the cycle. Irreversibility causes the system performance to degrade. The losses in the cycle need to be evaluated considering individual thermodynamic processes that make up the cycle. Energy (first law) analysis is still the most commonly used method in the analysis of thermal systems. The first law is concerned only with the conservation of energy. It does not provide information on how, where, and the amount of performance is degraded. As a complement to the present materials and energy balances, exergy calculations can provide increased and deeper insight into the process, as well as new unforeseen ideas for improvements. The relationship between energy and exergy, exergy and the environment, energy and sustainable development, and energy policy making details are reported (Dincer, 2002). Exergy analysis is a powerful tool in designing, optimization, and performance evaluation of energy systems. The principles and methodologies of exergy analysis are well established. An exergy analysis is usually aimed to determine the maximum performance of the system and to the sites of exergy destruction.

Exergy analysis of a complex system can be performed by analyzing the components of the system separately. Identifying the main sites of exergy destruction shows the direction for potential improvements. An important objective of exergy analysis for systems that consume power such as refrigeration, liquefaction of gases, and distillation of water is finding the minimum power required for a certain desired result (Kanoglu M, 2002). The performance of a refrigeration cycle using Freon-12 as the refrigerant based on the exergy analysis was investigated (Leiden frost, 1980). A heat pump system was experimentally studied that uses water as the heat source and heat sink (Akau and Schoenhals, 1980). The experimental results of the exergy analysis of a solar assisted heat pump system were presented (Kaygusuz and Ayhan, 1993). They investigated the effects of various parameters on the system performance. The conventional view expressed that the exergy efficiency of the actual refrigeration cycles does not depend on the refrigeration temperature (Bejan, 1989). The exergy efficiencies decrease as the refrigeration temperature decreases (Strobridge, 1974). In this paper, exergy analysis is applied to the Joule - Thomson refrigeration cycle. The expressions for the exergy efficiency and exergy loses (lost works) and pressure losses for the individual processes that make up the cycle as well as the coefficient of performance (COP) and second law efficiency for the entire cycle are analyzed. Effects of condensing and evaporating temperatures on the exergy losses, second law efficiency and COP are investigated. In many refrigeration systems, it is shown that refrigerants and lubricants mixture is the factor for performance. For global warming problem and ODP, hydrocarbons are used as a refrigerant and mineral oils are their lubricant. Different hydrocarbon mixtures are tested in the different experiments (V. Natarajan and S. Vanitha, 2015). However, still now there is no unique solution for that concern. More analysis is necessary to have a concluded decision for refrigeration system. Energy as well exergy analysis is necessary to achieve greater output and system with high performance.

EXPERIMENTAL SETUP AND INSTRUMENTATION

The schematic of the experimental set up developed in this experimental work is shown in Figure 1. The fabricated compact heat exchanger is integrated between the condenser and the expansion device. The front view (Figure 2) and rear view (Figure 3) of the experimental set up are exposed. The counter flow of refrigerant in the heat exchanger is preferred. The hot fluid and cold fluid flows through the inner tube and outer tube of the compact heat exchanger respectively. The outlet of the condenser is given as hot input to the heat exchanger and the output is passed as inlet to the expansion device. The outlet from the evaporator is given as cold input and output is passed as inlet to the compressor to repeat the cycle.

The heat exchanger having a surface area density on any one side is greater than700 m^2/m^3 is referred to as a compact heat exchanger regardless of its structural design. Tube-in-Tube type of compact heat exchanger has been fabricated and tested in this work. The compactness is 4500 m^2/m^3. The specification of main components of the compact heat exchanger is indicated in Table 1. Profile projector is used to measure the size of mesh opening in the disc and also the number of mesh openings in the disc is noted. By using screw gauge the wire diameter of the mesh and the thickness of the mesh are measured. The meshes were cut by using dies to fit in the space between inner and outer tubes through which one of the fluids will pass through. After cutting it to the required size, meshes are put one by one in small wires of length just greater than 315 mm. Then these meshes are put in the space between the tubes. About 224 discs are incorporated in the annular space and 250 discs of diameter equal to the inner tube diameter are filled in the inner tube of this heat exchanger. Before doing the above said operation the copper tubes are cut according to the required length. The cutting operation is done by means of a tube cutter. The outer tube and inner tube are cut for a length of 315 mm. In the same way the inlet and outlet tube for tube is also cut. Usually some amount of burrs is present during cutting which can be removed by using a half round file. Then the inner tube is placed inside the outer tube and is kept within by using copper plates using the brazing process. Just before the brazing process holes have drilled to let in and out the flow from the tube.

PROPERTIES OF NANOPARTICULATED OXIDES

The current knowledge on oxide materials allows affirming that most of their physico-chemical properties display acute size dependence. Physico-chemical properties of special relevance in Chemistry are mostly related to the industrial use of oxides as sensors, ceramics, absorbents and/or catalysts. A bunch of novel application within these fields rely on the size-dependence of the optical, (electronic and/or ionic) transport, mechanical and, obviously, surface/chemical (redox, acid/base) properties of oxide nanomaterials. We should stress that size effects in oxide chemistry have frequently two interrelated faces, structural/electronic quantum-size and size-defect or non-stoichiometry effects. Hence, here we will describe the influence of these two phenomena in the main physico-chemical properties of oxides.

CHEMICAL PROPERTIES

Metal oxides are used for both their redox and acid/base properties in the context of Absorption and Catalysis. The three key features essential for their application as absorbents or catalysts are the coordination environment of surface atoms, the redox properties and the oxidation state at surface layers. Both redox and acid/base properties are interrelated and may attempts can be found in the literature to establish correlations of both properties. In a simple classification, oxides having only s or p electrons in their valence orbitals tend to be more effective for acid/base catalysis, while those having d or f outer electrons find a wider range of uses. The solid in a given reaction conditions that undergoes reduction and oxidation simultaneously by giving out surface lattice oxygen anions and taking oxygen from the gas phase is called a redox catalyst. This process necessarily demands microscopy reversibility and implies dynamic operation. Based on modern isotopic exchange experiments, the redox mechanism of chemical reactions can be more specifically divided in extra facial oxygen in which adsorbed (oxygen) species react (electrophilic reaction) and interfacial oxygen where lattice oxygen vacancies are created (nucleophilic reaction). There are enormous evidence that nucleophilic oxygen is capable of carrying out selective oxidations while it seems that electrophilic species seems to exclusively work on non-selective ones. Latter, it was shown that hydrocarbon selective oxidation starts with H-abstraction steps and that the filling of oxygen vacancies require the cooperation of a significant number of cations. So, typically, an oxidation reaction demands to optimize three important steps: the activation of the C-H bond and molecular oxygen, and the desorption of products (to limit over-oxidation). The effect of size on these key steps is unknown but can be speculated to be related to the oxidation state of surface cations and their ability to manage electrons and the influence of non-stoichiometry on the gas-phase oxygen species handling and activation.

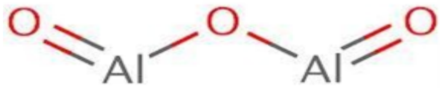


Figure.1.Bonding structure of Aluminium Oxide

PREPARATION OF NANO LUBRICANTS

The nanoparticles of Al_2O_3 in the range 40-50 nm were mixed with POE to synthesize Nano lubricant in a recommended method for Nano fluid. POE oil was used as supplied by supplied without further purification. The nano particles of Al_2O_3 and POE mixture were prepared with the aid of magnetic stirrer for 2 hrs. The mixture is then further kept vibrated with an ultrasonic homogenizer for half an hour to fully separate the nanoparticles and to prevent any clustering of particles in the mixture to obtain proper homogenization. No surfactant is added in this work as there may be any influence in reduction of thermal conductivity and performance.

EXPERIMENTAL PROCEDURE

Initially, the system was purged with nitrogen gas to check leakage, to remove impurities, moisture and other foreign materials inside the system, which may affect the accuracy of the experimental results. Then the setup was charged with R134a with POE, the baseline tests were carried out. The refrigeration capacity and coefficient of performance, exergy flow rates of each component and piping of refrigeration system were calculated. The properties are calculated using software Aspen version 11.1 using Peng – Robinson equation of state. Cycle performance determination is performing to ease the theoretical calculations by means of some assumptions as follows: steady state processes; neglect of pressure drops and heat losses to the environment from the devices of evaporator, heat exchanger, condenser and capillary tube.

The detailed baseline tests procedure of the experimental setup charged with R134a with POE are as follows,

1. The refrigerant is charged with the maximum pressure in the compressor and allowed to run. After reaching the steady state condition, the pressure gauge readings and the temperature sensors readings were taken.
2. The compressor charged pressure of the refrigerant is slightly reduced by releasing the refrigerant from the system. Then the setup is allowed to run and after achieved the steady state the readings were taken. A number of readings were taken until the pressure of the refrigerant supported to change in the evaporator inlet temperature.

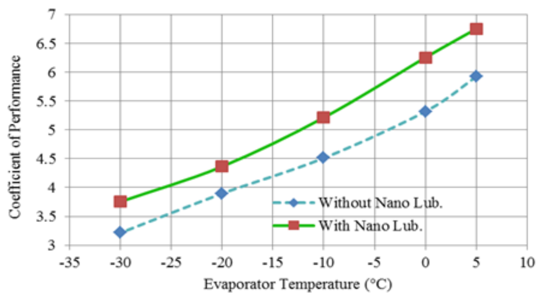


Figure.2.Coefficient of performance of the refrigerants with and without Nano lubricant

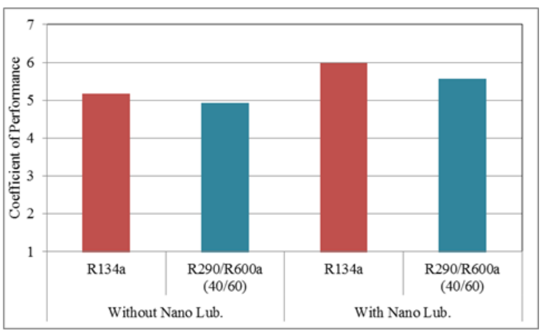


Figure.3.Coefficient of performance vs evaporator temperature with R290/R600a (40/60)

The system was evacuated by using a vacuum pump. Then the system has been charged with the mixtures of hydrocarbon refrigerants R290/R600a (40/60) charged with POE and the experiments are conducted by following the procedure 1 and 2. Then, the Nano lubricant (Al_2O_3 and POE mixture) was charged in the system. The refrigerants R134a and blend of R290/R600a (40/60) were charged one after another. The procedure 1 and 2 was repeated and readings are taken. Figure 2 shows the result with R290/R600a (40/60) mixed refrigerant performs as close to the systems with R134a as a refrigerant. Therefore, it is recommended that R290/R600a (40/60) could be a suitable environment friendly replacement for R134a refrigerant. Further in order to compare the system performances with and without Nano lubricant, the results obtained using the above refrigerant is selected and different performance parameters are discussed.

Figure 3 shows the coefficient of performance comparison between the system with and without Nano lubricant. The system with Nano lubricant yields higher coefficient of performance than that of the system without Nano lubricant by 14.03% - 16.81%. This is due to reduction in isentropic compression work and increases in the refrigerating effect. Figure 4 shows the efficiency defect in compressor. It is found to be 17.07% - 44.21% lower by the system with Nano lubricant compared with the system without Nano lubricant. The efficiency defect in condenser for the system with and without compact heat exchanger is shown in the Figure 5. The system with Nano lubricant has lower than that of the system without Nano lubricant by 10.22% - 16.91%. Figure 6 shows the Efficiency defect in capillary tube of the system with and without Nano lubricant. The system with Nano lubricant has lower than that of system without Nano lubricant by 2.33% - 2.56%. The efficiency defect in evaporator for the system with and without Nano lubricant is shown in the Figure 7. The system with Nano lubricant has lower than that of the system without Nano lubricant by 39.88% - 64.51%. The exergetic efficiency of the system with and without Nano lubricant is shown in the Figure 8. The system with Nano lubricant obtained higher than that of the system without Nano lubricant by 10.92% - 5.27%. The result shows the system efficiency improved for the system with Nano lubricant. Figure 9 shows the exergy destruction ratio of the system with and without Nano lubricant. The system with Nano lubricant has lower than that of the system without Nano lubricant by 20.48% - 10.29%. The result shows the system with Nano lubricant has less wasted work potential.

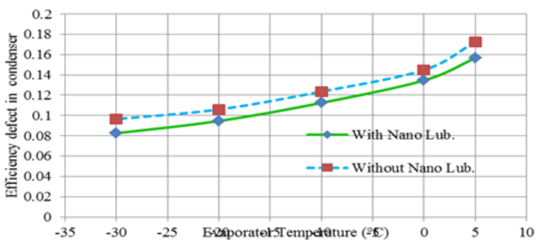


Figure.4.Efficiency defect in compressor vs evaporator temperature with R290/R600a (40/60)

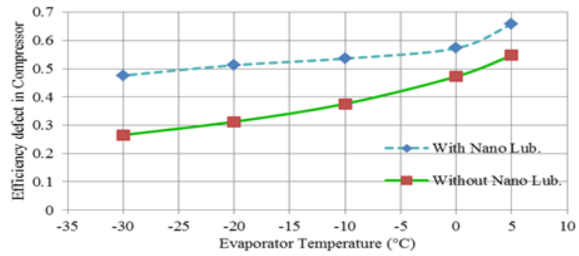


Figure.5.Efficiency defect in condenser vs evaporator temperature with R290/R600a (40/60)

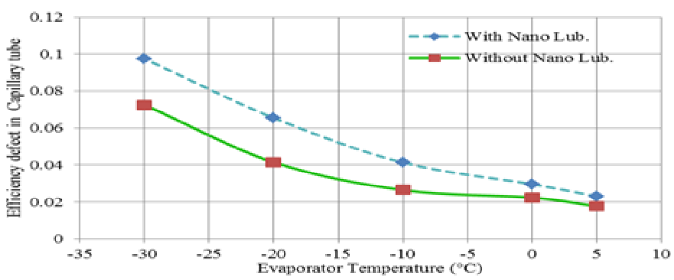


Figure.6.Efficiency defect incapillary tube vs evaporator temperature with R290/R600a (40/60)

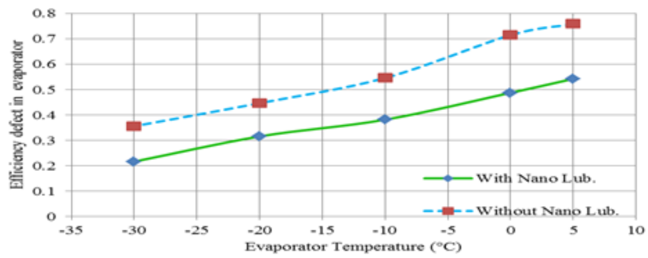
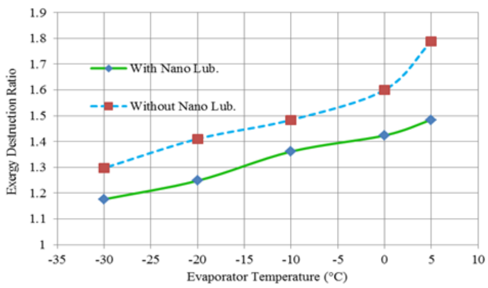


Figure.7.Efficiency defect in evaporator vs evaporator temperature with R290/R600a (40/60)



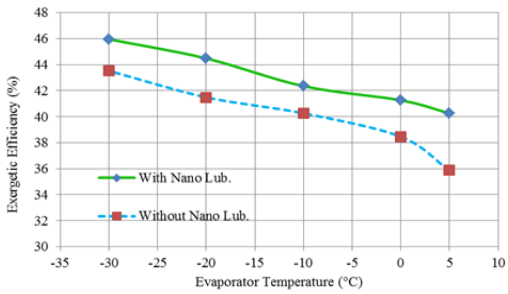


Figure.8.Exergetic efficiency vs evaporator temperature with R290/R600a (40/60)

Figure.9.Exergy destruction ratio vs evaporator temperature with R290/R600a (40/60)

CONCLUSION

Joule – Thomson refrigeration system with nano lubricant provide better results than the system without nano lubricant. The Joule – Thomson refrigeration system with nano lubricant yield the coefficient of performance 13.31% greater than the system without nano lubricant by using R134a. The experimental results shows R290/R600a (40/60) obtained the coefficient of performance closer to R134a in both the systems. The experimental system with nano lubricant yields the exergetic efficiency 4.25% higher than without nano lubricant. The exergy destruction ratio of the experimental results shows 7.398% lesser for the system with nano lubricant compare to system without nano lubricant. The experimental results of the exergy destruction ratio 9.34% lesser for the system with nano lubricant compare to without nano lubricant.

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