

# Performance Evaluation of A Household Refrigerator Using CuO Nanoparticle Lubricant Mixture and Various Other Compressor Oils with Different Condenser Modes

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**Abstract:-** The objective of this paper was to study the performance of household refrigerator having both air and water-cooled condenser, with 0.06% mass fraction CuO nanoparticle-lubricant mixture and different types of compressor oils. The experiment was done using HFC134a as the refrigerant, CuO nanoparticles, Polyol-ester oil (POE) oil which is used as the conventional lubricant in the household refrigerator and SUNISO 3GS mineral oil as the lubricant alternatively. The result indicates that the refrigerator performance had improved while using CuO nanoparticle-lubricant mixture. The performance was also improved when HFC134a/SUNISO 3GS mineral oil system was used instead of HFC134a/POE oil system and there was also an enhancement when water-cooled condenser was used instead of the conventional air-cooled condenser on all load conditions. The HFC134a/CuO/SUNISO 3GS mineral oil system works normally and safely in the refrigerator. HFC134a/CuO/SUNISO 3GS mineral oil system reduced the energy consumption between 12% and 19% when compared with the HFC134a/POE oil system and between 9% and 14% while working with water-cooled condenser on various load conditions. There was also an enhancement in coefficient of performance (COP) when CuO nanoparticle-lubricant mixture was used instead of POE oil as the lubricant. The water cooled heat exchanger was designed and the system was modified by retrofitting it, along with the conventional air-cooled condenser by making a bypass line and thus the system can be utilized as a waste heat recovery unit. Experimental result shows that about 200 litres of hot water at a temperature of about 58°C over a day can be generated. Techno economic analysis shows that the installation cost and running cost of the waste heat recovery system for a day is much lower than that of a conventional

**Keywords:-** Household refrigerator, HFC134a, Water-cooled condenser, CuO nanoparticles, POEoil, Suniso 3GS mineral oil

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## I. INTRODUCTION

A household refrigerator is a common household appliance that consists of a thermally insulated compartment and which when works, transfers heat from the inside of the compartment to its external environment so that the inside of the thermally insulated compartment is cooled to a temperature below the ambient temperature of the room. Heat rejection may occur directly to the air in the case of a conventional household refrigerator having air-cooled condenser or to water in the case of a water-cooled condenser. Tetrafluoroethane (HFC134a) refrigerant was now widely used in most of the domestic refrigerators and automobile air- conditioners and are using POE oil as the conventional lubricant. Heat can be recovered by using the water-cooled condenser and the system can work as a waste heat recovery unit. The recovered heat from the condenser can be used for household applications like bathing, cleaning, laundry, dish washing etc. The modified system can be used both as a refrigerator and also as a water heater. Therefore by retrofitting a water-cooled condenser it produce hot water and even reduce the utility bill of a small family. In this system the water-cooled condenser is designed as a tube in tube heat exchanger of overall length of 7m. It consists of an inlet for the cooling water and an exit for collecting the hot water. The hot water can be used instantly or it can be stored in a thermal storage tank for later use.

S.S. Hu, B.J. Huang et al. [1] conducted an experimental investigation on a split air conditioner having water cooled condenser. They developed a simple water-cooled air conditioner utilizing a cooling tower with cellulose pad filling material to cool the water for condensing operation. The experimental investigation verified that the water-cooled condenser and cooling tower results in decreasing the power consumption of the compressor.

H.I. Abu-Mulaweh [2] designed and developed a thermosyphon heat recovery system which can recover heat from a window air conditioner. They designed two types of heat exchangers, concentric type heat

exchanger and coiled heat exchanger and then it is retrofitted in to the air conditioning system. They analysed the performance of the system with these two types of heat exchangers. The circulation of water through the heat exchanger is done with the themosyphon effect which completely eliminates the need of a pump. For having that, the heat exchangers are connected to a water storage tank and when the water in the heat exchanger get heated up by the superheated refrigerant the hot water flow upward through the connecting pipe into the top of the storage tank and at the same time the cold water from the bottom of the tank will flow into the heat exchanger. The test results show that the concentric heat exchanger produce hot water at a temperature of 45°C and the coil type produced hot water having 40°C.

Sheng-shan Bi et al. [3] experimentally investigated the performance of a domestic refrigerator with SUNISO 3GS mineral oil and TiO<sub>2</sub> nanoparticles in the working fluid. The results indicated that the energy consumption of the HFC134a refrigerant using SUNISO 3GS mineral oil and 0.06% mass fraction of TiO<sub>2</sub> nanoparticle mixture as lubricant reduced the energy consumption by 21.2% when compared to that of HFC134a and POE oil system.

Romdhane ben slama [4] developed a system that can recover heat from the condenser of the refrigerator. In this work the air-cooled conventional condenser is replaced by another heat exchanger to heat the water. The results show that water at a temperature of 60°C was produced by the system. This paper also analysed the economic importance of the waste heat recovery system from the energy saving point of view.

Shengshan Bi et al. [5] experimentally investigated the performance of a domestic refrigerator using TiO<sub>2</sub>-R600a nano-refrigerant. The test results shows that refrigerator performance was better than the pure R600a system, with 9.6% less energy used with 0.5 g/L TiO<sub>2</sub>-R600a nano- refrigerant.

## II. EXPERIMENTAL SETUP

### A. Experimental System

The refrigerator was of 190L capacity, single door, manufactured by Kelvinator. The system was retrofitted with a water-cooled condenser along with the conventional air-cooled condenser by making a bypass line. Water-cooled condenser is a tube in tube heat exchanger having an inlet for the cooling water and an exit for collecting the hot water. The modified household refrigerator was properly instrumented with temperature indicators, pressure gauges and digital energymeter. The temperature at various points was noted using calibrated K-type thermocouples. The calibration of thermocouple was performed in comparison with the Standard Platinum Resistance Thermometer (SPRT). Pressure gauges used in this experiment are of bourdon tube type gauges. Dead weight pressure gauge tester using the principle of Pascal’s law was used as the calibration equipment. Evaporator and condenser pressure are noted using calibrated pressure gauges. The power consumption of the domestic refrigerator was measured by using a digital energymeter. Figure 1 shows the experimental test rig. The retrofitted water- cooled condenser can also be seen. The refrigerator specification is given in Table 1.



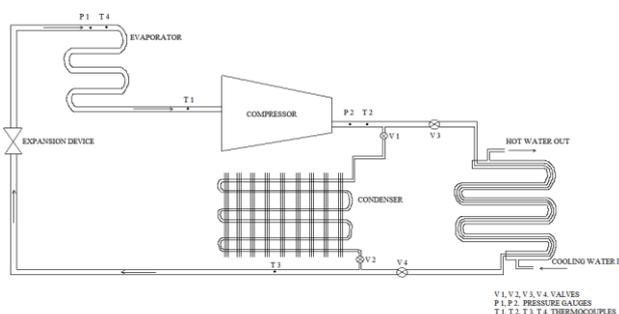
Fig. 1 Experimental test rig

TABLE 1: REFRIGERATOR SPECIFICATIONS

Gross capacity	190 L
Refrigerant	HFC134a
Charged mass	140 g
Compressor type	Hermetic

## B. Experimental procedure

Schematic diagram of the experimental apparatus is shown in Figure 2. The valve V 3 and V 4 was closed to make the system work only with air-cooled condenser and similarly valve V 1 and V 2 was closed to make the system work only with water-cooled condenser. The system was operated at five load conditions namely, No load, 40W, 100W, 160W and 200W. At each load conditions temperature and pressure at salient points were noted down at every five minutes interval. The temperature of the water at inlet and exit was also measured.



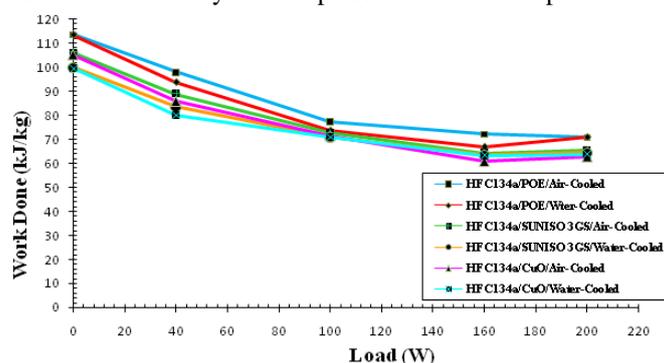
**Fig. 2** Schematic diagram of the experimental apparatus

The experiment was done until steady state condition was attained in the evaporator. The energy consumption of the system is measured using a digital energymeter. The performance of the refrigerator was first measured using HFC134a/POE oil as the working fluid then by using HFC134a/SUNISO 3GS mineral oil and finally by HFC134a/CuO/SUNISO 3GS mineral oil in both air/water-cooled condenser mode. The test results of HFC134a/POE oil system, HFC134a/ SUNISO 3GS mineral oil system and HFC134a/CuO/SUNISO 3GS mineral oil system were compared in both air/water-cooled condenser modes.

## III. RESULTS AND DISCUSSIONS

Figure 3 gives the comparison of the work done by the compressor with HFC134a/POE oil, HFC134a/SUNISO 3GS mineral oil and HFC134a/CuO/SUNISO 3GS mineral oil. The work done by the compressor was greater for the HFC134a/POE oil system than the HFC134a/SUNISO 3GS mineral oil system. The work done was further reduced on using HFC134a/CuO/SUNISO 3GS mineral oil system in both air/water-cooled condenser mode and similarly the work done by the compressor for the air-cooled system was higher than that of the water-cooled on all load conditions.

This was because the condenser-evaporator pressure difference was high for the system when operating with HFC134a/POE oil than the HFC134a/SUNISO 3GS mineral oil system and HFC134a/CuO/SUNISO 3GS mineral oil system. The pressure difference was also high when operating with air-cooled condenser instead of water-cooled condenser. As the work done by the compressor increases the power consumption also increases.



**Fig.3** Variation of work done with load

Figure 4 shows the COP variation of HFC134a/POE oil, HFC134a/SUNISO 3GS mineral oil and HFC134a/CuO/SUNISO 3GS mineral oil. The COP was greater for the HFC134a/CuO/SUNISO 3GS mineral oil system on various load conditions. The COP of air-cooled condenser was also lower when compared to the water-cooled condenser on all load conditions in both lubricants. This may be due to the inverse proportionality of COP to work done on all load conditions.

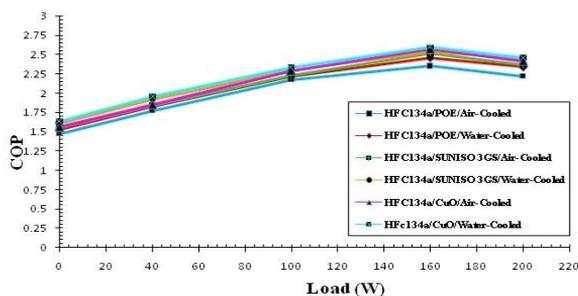


Fig.4 Variation of COP with load

Figure 5 shows the power consumption of the refrigerator. As the work done increases the power consumed by the system also increases. Power consumed by the compressor was less when the system was operating with water- cooled condenser. The power consumption of the system HFC134a/CuO/SUNISO 3GS mineral oil was also lower than others at various load conditions.

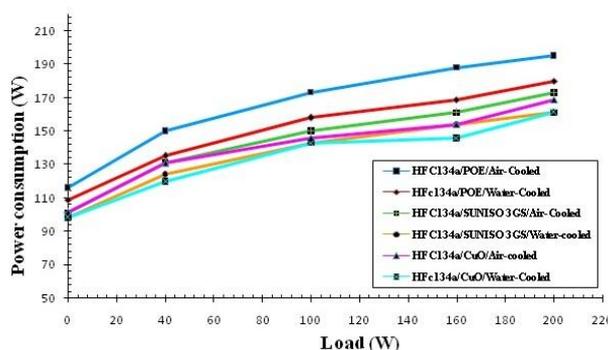


Fig.5 Variation of power consumption with load

The experimental result also shows that about 200 litres of hot water at a temperature of about 58°C over a day from the outlet of water-cooled condenser and thus analysed the economic importance of this waste heat recovery system from the energy saving point of view.

Table 2 provides the energy consumption of the HFC134a/POE oil, HFC134a/SUNISO 3GS mineral oil and HFC134a/CuO/SUNISO 3GS mineral oil air-cooled system at steady state for a time period of five minutes. Table 3 shows the energy consumption of the HFC134a/POE oil, HFC134a/SUNISO 3GS mineral oil and HFC134a/CuO/SUNISO 3GS mineral oil water-cooled system at steady state for a time period of five minutes.

**TABLE 2:** Energy Consumption Of Hfc134a/Poe Oil, Hfc134a/Suniso 3gs Mineral Oil And Hfc134a/Cuo/Suniso 3gs Mineral Oil For Air-Cooled Condenser

Load (W)	HFC134a/POE oil Energy consumption (kWh)	HFC134a/SUNISO 3GS oil Energy consumption (kWh)	HFC134a/CuO/SUNISO 3GS oil Energy consumption (kWh)	Energy saving (%)
No load	0.00969	0.00844	0.00843	13.00
40	0.01250	0.01094	0.01094	12.48
100	0.01438	0.01250	0.01219	15.23
160	0.01563	0.01344	0.01281	18.04
200	0.01625	0.01438	0.01406	13.48

**TABLE 3:** Energy Consumption Of Hfc134a/Poe Oil, Hfc134a/Suniso 3gs Mineral Oil And Hfc134a/Cuo/Suniso 3gs Mineral Oil For Water-Cooled Condenser

Load (W)	HFC134a/ POE oil Energy consumption (kWh)	HFC134a/ SUNISO 3GS oil Energy consumption (kWh)	HFC134a/ CuO/SUNISO 3GS oil Energy consumption (kWh)	Energy saving (%)
No load	0.00906	0.00813	0.00813	10.26
40	0.01125	0.01031	0.01000	11.11
100	0.01313	0.01188	0.01188	9.52
160	0.01406	0.01281	0.01219	13.30
200	0.01500	0.01344	0.01344	10.40

#### IV. TECHNO ECONOMIC ANALYSIS

1) Techno economic analysis was done by comparing the system with the conventional geyser (water heater). The geyser selected is the most sold type in India. The capacity of geyser is 10 litres and the power rating of it is 1500W. The comparison between the geyser and the developed waste heat recovery system is shown in Table 4. The water collected in one day is less compared to a geyser but this amount is enough for the hot water requirement of a small family. The power consumption of the system is actually used for refrigeration purpose and not for heating. By the modification of the conventional system into a refrigerator-cum-water heater, the waste heat liberated into the surrounding is recovered and used for heating the water. So the system is actually producing free hot water, i.e. the system will give hot water without consuming any extra energy for its operation.

**TABLE 4:** Comparison Between Geyser And Waste Heat Recovery System

	Geyser	Waste heat recovery system
Cost	₹ 6670	₹ 1868
Time taken in minutes to collect 10 litres of water	15	77
Energy consumed in (W) for producing 10 litres of hot water	3580	2249
Cost of collecting 10 litres of hot water	₹ 0.34	₹ 0.22
Power consumed in (kW) one day	344	42
Cost of 24 hourr operation	₹ 32.64	₹ 4.11
Water collected in litres in one day	960	180

## V. CONCLUSIONS

The advantages of using CuO nanoparticle-lubricant mixture and SUNISO 3GS mineral oil as the lubricant instead of POE oil in a household refrigerator with air/water-cooled condenser was investigated experimentally. The main conclusions are listed as follows:

- (1) The HFC134a/CuO/SUNISO 3GS mineral oil and HFC134a/SUNISO3GS mineral oil system worked normally and efficiently in the household refrigerator
- (2) The energy consumption of the HFC134a refrigerator using CuO nanoparticle-lubricant mixture reduced the energy consumption of the household refrigerator system between 12% and 19% for air-cooled condenser and between 9% and 14% for water-cooled condenser and on using SUNISO 3GS mineral oil as the lubricant the energy consumption reduced between 11% and 15% for air-cooled condenser and between 8% and 11% for water-cooled condenser on various load conditions.
- (3) The results confirmed that the performance of refrigerator with the HFC134a/CuO/SUNISO 3GS mineral oil system was better than that of the HFC134a/POE oil system and there was an improvement in the operation when the refrigerator works with water-cooled condenser.
- (4) POE oil is known to be hygroscopic and hydrolytic, so there are many problems in refrigeration systems using POE oil such as wadding deposition, bulging equipment that chokes the flow and severe friction in the compressor. The SUNISO 3GS mineral oil completely eliminates these problems, not only this SUNISO 3GS mineral oil is having excellent chemical stability. They do not precipitate wax deposit in an extremely low temperature section of the system such as valve or evaporator. SUNISO 3GS mineral oil is having better fluidity at low temperature condition resulting good oil returning in the refrigeration systems. These outstanding features may be the reasons for the better performance of the household refrigerator with the HFC134a/SUNISO 3GS mineral oil system than that of the HFC134a/POE oil system.
- (5) The better performance of CuO nanoparticle-lubricant mixture may be due to the enhancement of the solubility of the HFC134a and mineral oil as indicated by the high oil return ratio.
- (6) About 200 litres of hot water at a temperature of about 58°C over a day from the outlet of water cooled condenser and this modification made the household refrigerator to be work as both refrigerator and water heater. The hot water which was obtained from the water-cooled condenser can be utilised for household applications like cleaning, dish washing, laundry, bathing etc.
- (7) An economic analysis was done by comparing the system with the conventional geyser and it was found that the installation cost and running cost of the waste heat recovery system for a day is much lower than the geyser. However the water collected in one day is less compared to a geyser but this amount is enough for the hot water requirement of a small family.

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