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# Performance analysis of nano particle eco friendly chilling plant for fish processing

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■ **ABSTRACT :** In the present work, the feasibility of utilizing R404a as refrigerant along with nano particles ($Al_2O_3$, CuO and $TiO_2$) as additives in nano particle eco friendly chilling plant for fish processing. The performance analysis used three different nano particles each with five combinations for the assessment for R404a. The best performance of the system was identified using the comparison of system parameters like COP, compressor work input, refrigerating effect, compressor suction and discharge pressure and temperature at all the state points of the system. COP analysis of R404a with nano particle of $Al_2O$, CuO and $TiO_2$. Since the emphasis has been laid on COP and evaporating temperature not given primary importance and hence the study concludes that the mixture of R404a offering the COP of 3.97 with 3% CuO having 29.6 kj/kg-K work input to the compressor along with highest refrigerating effect of 119.40 kj/kg-K can be used as an alternative refrigerant for nano particle eco friendly chilling plant for fish processing at the temperature range of -11°C. The performance characteristics of the system may provide a guideline for the cold chain application in fisheries and its allied applications.

■ **KEY WORDS :** Percentage of nano particle, Eco friendly chilling plant, Refrigeration effect, Co-efficient of performance (COP)

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In 1956 G.M.B Dobson measured the ozone level in the Arctic region as 320 DU (Dobson units) and it was below 150DU during spring time, when compared to the normal level of 450DU, which was an unknown phenomenon and was named as ozone hole. Before the harmful effect on the ozone layer was identified in 1974 by Frank Sherwood Rowland and his postdoctoral associate Mario J. Molina in comparison with nitric oxide produced by soil bacteria through the production of $NO_2$, the CFC's lead the world of refrigeration industries for over 6 decades.

In early 1980's scientists have identified the steady decline of about 4% per decade in the total volume of ozone in earth's stratosphere (the ozone layer) which is known as ozone depletion and a much larger springtime decrease in stratospheric ozone over earth's polar regions named as ozone hole comparing to the ozone layer measured earlier in Dobson units abbreviated as "DU". These components greatly contributed towards global warming and also quantified it as 8500 times more than that of $CO_2$ over a hundred years. These findings kindled the interest of HVAC engineers on production and the usage of HFC and HC refrigerants and also the ban on CFC's and HCFC's as the Montreal protocol agreement on 16th September 1987 and came into force on 1st January 1989. According to the Montreal protocol signed in 1989 the refrigerants which are friendly to environment with zero ozone depletion potential and near zero global warming potential are required to be used in refrigerators and HVAC systems to regulate production and trade of the ozone-depleting substances such as CFC's and HCFC's.

The London, Copenhagen, Montreal and Beijing amendments came into force on 10th August 1992, 14th June 1994, 10th November 1999 and 25th February 2002 which were responsible for the established of final expiration of HCFC's as 2030. So the search continues on the possible alternatives for the refrigerants which are acceptable interms of thermophysical, thermodynamic properties and less harmful for the environment. Even though the protocol banned the production and usage of CFC's, it gave a ten year grace period to the developing nations for the usage of these refrigerants with less than 0.3kg per capita and special help to minimize the usage.

Michael Uhlmann and Stefan S. Bertsch (2012) have derived the improved control strategies for heat pumps using on-off cycling as capacity control through the evidence of performance losses of 1 - 2% for short cycling times of air source heat pumps and 5% efficiency gain in the case of geothermal heat pumps by the recovery of the ground probe during the off time. Lee *et al.* (2002) have suggested the numerical code to predict the performance of Condenser and found the acceptable deviation of calculated and experimental values with the use of R-22 were 10.1% greater than experiment data and with the use of R-407C the results were 10.7% less than experiment data and thus they suggested the numerical code to be used as a design tool to develop better condenser paths.

Gao *et al.* (2012) have studied the absorption refrigeration system with the binary mixture of trifluoromethane (R23) and N,N-dimethyl formamide as a promising new working fluid and found the average relative deviation of 1.8% between experimental and calculated values of system parameters. Bansal *et al.* (2012) have studied the alternative technologies for refrigeration such as thermo-acoustic refrigeration, thermoelectric refrigeration, thermo-tunneling, magnetic refrigeration, Sterling cycle refrigeration, pulse tube refrigeration, Malone cycle refrigeration, absorption refrigeration, adsorption refrigeration, and compressor driven metal hydride heat pumps. They suggested going for integrated heat pump system serving both heating and air conditioning applications in domestic applications.

Boissieux *et al.* (2000) studied with the use of Mixtures R407C (R32/R125/R134a of quality 0.23:0.25:0.52), R404a (R125/R143a/R134a of quality 0.44:0.52:0.04) and Isceon 59 (R125/R134a/R600 of quality (0.47:0.50:0.03) and stated that the Dobson and Chato correlation provided the best prediction for these refrigerant mixtures and the Shah correlation fitted the measurements of the local heat transfer co-efficients well and seems to cope well with refrigerant mixtures.

Wang *et al.* (2012) have confirmed the normal working of residential air conditioners with the use of the mixture of R410a/MNRO as working fluid. The cooling/heating energy efficiency ratio of the residential air conditioners increased about 6% by replacing the polyol-easter oil VG 32 lubricant with MNRO (mineral-based nano-refrigeration oil).

Chen and Yu (2008) have confirmed the new refrigeration cycle having the evaporator circuit of two branches to realize Lorentz cycle with the advantage of temperature glide (NRC) using the binary non-azeotropic refrigerant mixture (R32/R134a) results in 8 to 9% COP raise and 9.5% increase in volumetric refrigerating capacity. Park and Jung (2009) have reduced the charge of the system upto 58% due to its low liquid density and found that the COP of the system using mixture of R170/R290 of quality 0.06:0.94 was higher than that of R22 and have 16.6–28.20C lower compressor discharge temperatures, this in turn increases the life of the system.

Fernando *et al.* (2004) have performed a study on traditional refrigeration system under typical Swedish condition and found that the charge of about 200 grams is the best choice for the heat pump providing a COP between 3.5 and 4 using R290 as a refrigerant. Jung *et al.* (2000) have examined the performance of R290 / R600a mixture of quality or mass fraction 0.6 : 0.4 in domestic refrigerators and suggested the COP increase of 2.3%. Three to four percentage (3-4%) of higher energy efficiency at faster cooling rate as well as shorter compressor on-time and lower compressor dome temperatures were confirmed with this mixture compared to CFC12 – R12.

Cleland *et al.* (2009) have quantified the system performances and stated that the system with mixture of propane and ethane (Care-50) reduced energy use by 6–8% under similar system cooling capacity relative to HCFC-22. With propane (Care-40), energy use decreased by 5% but cooling capacity was 9% lower. Anand and Tyagi (2012) have revealed the fact that the exergy destruction is least when the system is 25% charged and also COP of the system is high when the system is 50% charged due to higher refrigerating effect and reduced compressor work and exergy efficiency of the system is highest when the system is 100% charged. So he suggested that the system must run with the optimum balance between the exergy efficiency and energy savings.

Andrey Rozhentsev and Vjacheslav Naer (2009) have studied the stationary modes the operating parameters of the system using 3-component non-azeotropic mixtures of hydrocarbons – isobutane ($CH(CH_3)_2CH_3$) / ethane ($CH_3CH_3$) / methane $CH_4$) as a refrigerant which corresponded to their design / calculated values varying with the refrigerant working mixture compositions and ambient temperatures (that is the heat load) within the following ranges: discharge pressure – (12.3, ..., 13.4) bar; suction pressure – (0.8, ..., 1.3) bar; compressor input power – (385, ..., 435) W. The air temperature in the low-temperature chambers of the $1^{st}$ and $2^{nd}$ type for the considered modes was as low as (-80, ..., -95)$^0$C while the average temperature along the evaporator was of (-85, ...,-105)$^0$C, correspondingly.

Lee *et al.* (2002) have predicted the effect of the refrigerant change from R22 to R407C on the chiller performance and measured that the cooling capacity decreases by 10–20% and the COP by 20–30% depending on the temperature condition. It is found that the main reason for the decrease in the Chiller performance is the decrease in the heat transfer co-efficient of R407C compared with that of R22 based on the three factors which are thermodynamic properties, compressor efficiency, and heat transfer.

## ■ METHODOLOGY

### Experimental set up:

The Fig. A shows the experimental setup consists of three compressors for accommodating three different nano particles along with individual oil separate (ensuring no nano particle beyond oil separator along the refrigerant cycle, air cooled condenser (assisted by fan), thermostatic expansion valve and an evaporator section. The compressor used in this system is Kirloskar KCN414LAL-B230H. A four row air cooled condenser of 1TR capacity is used to facilitate the proper condensing area ensuring the system pressure never increases beyond a limit. An individual oil separator was connected to separate the oil and nano particle correspond to its compressor from the compressor discharge and the separated oil and nano particle was directed to the compressor doom through the suction line of the compressor. Charging valves of individual nature were also provided to facilitate the charging for performance testing. The experimental setup was placed on a platform along with a blast freezer type evaporator unit capable of handling -20°C inside.

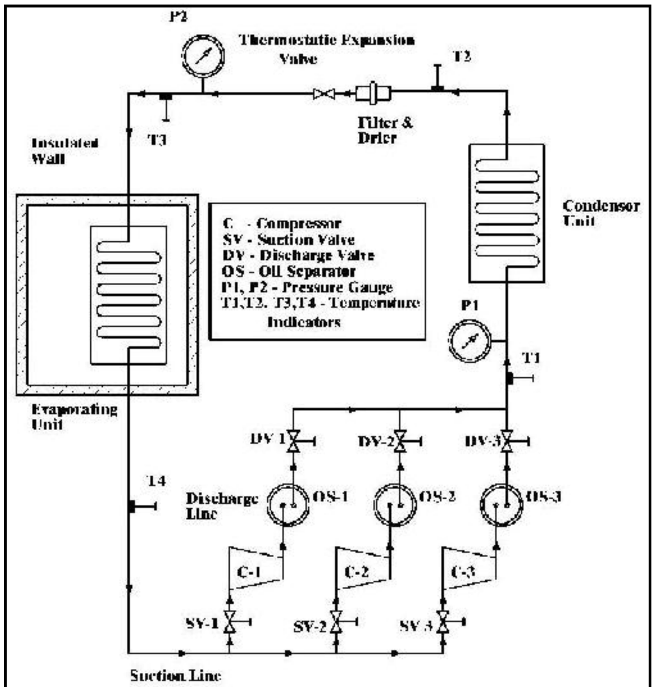


**Fig. A : Schematic diagram of experimental setup of nano particle eco friendly chilling plant for fish processing**

This setup was used for conducting COP analysis of R404a with nano particle of $Ag_2O$, CuO and TiO2. For the realization of different requirements of each compressor this nano particled eco-friendly refrigeration unit considered the TES2:068Z3403 with orifice sizes of "1", in size to accommodate the variation in cooling load. Thermometers and pressure gauges are used to measure the temperatures and pressures of the unit at various places as well as suction and discharge. Initially the system was flushed with nitrogen gas to eliminate impurities, moisture and other foreign materials inside the system, which may affect the accuracy of the experimental results. $Ag_2O$, CuO and $TiO_2$ were mixed with the compressor oil through suction valve provided for each comprssure and the R404a refrigerant is charged into the setup. Refrigerant is allowed to work and the COP for the system was analyzed. COP was found to be more when the nanoparticles were added rather than the COP of R404ac without nanoparticle. Temperatures and pressures are recorded at frequent intervals. The work input to the compressor, refrigerating effect and COP during tests was measured after attaining the steady-state condition during every testing trial. The measured values were used to study the performance characteristics of the refrigerator. Fig. B shows the photographic view of nano particle eco friendly chilling plant for fish processing.

**Fig. B : Photographic view of nano particle eco friendly chilling plant for fish processing**

## Refrigerant charging :

The system was subjected to leak test with nitrogen at 31.74 bar. The system was kept idle for 60 hours and checked for pressure drop to ensure zero leak. Then the system was evacuated to the vacuum level. After completing the evacuation test, the system was ready for charging the refrigerant mixture. Initially high boiling refrigerant was charged through charging valve followed by medium boiling refrigerant and then by the low boiling refrigerant as per the thermodynamically correct mass fraction. A digital mass balance was used to have accurate mass of charged quantity.

After charging the mixture with desired mass fraction, the system was started with uniform ambient temperature. Before starting the system, pressures at discharge side and suction side were equalized by the use of the bypass line and extra volume to ensure less starting torque of the compressor. After the starting of compressor the valve was closed. Different observations like temperatures at each state point, pressures at each state point, power consumption of compressor and evaporator heat load were recorded. All the observations were made after getting the equilibrium condition of the system. The equilibrium state was arrived by adjusting the heater load and evaporator refrigerating effect. The unchanged temperature of secondary medium ensured this equilibrium state.

The nano particle was charged at different composition for their corresponding compressors and before initiation they were checked for its correctness by digital physical balance with accuracy of 1 mg. The different combinational testing were executed and the readings were recorded for analysis.

## Heat leak test :

The heat leak test was carried out to find heat infiltration into the evaporator tank from ambient temperature and different secondary fluid temperatures. Initially the temperature of secondary fluid in the evaporator tank was brought down and then the system was stopped. Then the time taken for every one degree increment of secondary fluid temperature was recorded.

The non return valve connected at the end of the evaporator coil ensured no influence of back flow of refrigerant that would heat the secondary fluid. The heat infiltration was calculated using the following Eq. 1.

$$\text{Calorimeter Heat Gain} = (m.\ Cp.\ aT) / at \quad (1)$$

where, m is total mass of secondary fluid in the evaporator tank (kg)

Cp is specific heat of secondary fluid ($kJ\ kg^{-1}\ K^{-1}$)

$\Delta T$ is difference of initial and final temperature (ºC)

$\Delta t$ is time taken for $\Delta T$ increase of temperature

(seconds)

The calculated amount of evaporator heat infiltration for particular secondary fluid temperature was added to the load indicated in the wattmeter. Hence, the exact load on evaporator was estimated.

**Uncertainty analysis :**

$$Z_i = Z_i \pm \delta Z_i \quad (2)$$

The theoretical COP of the refrigeration system is expressed as

$$COP_{th} = \frac{h_{e,o} - h_{e,i}}{W_c} \quad (3)$$

Hence, the COP of the system is a function of enthalpy and work of compression, enthalpy is a function of pressure and temperature. The work of compression was given by

$$W_c = \left(\frac{n}{n-1}\right) * P_S * c * \left[\left(\frac{P_d}{P_s}\right)^{\frac{n}{n-1}} - 1\right] \quad (4)$$

The uncertainty in COP calculation using linear variables is expressed as (Holman, 2000),

$$\delta COP_{th} = \left[\left(\frac{\delta T_{e,i}}{T_{e,i}}\right)^2 + \left(\frac{\delta T_{e,o}}{T_{e,o}}\right)^2 + \left(\frac{\delta P_{e,i}}{P_{e,i}}\right)^2 + \left(\frac{\delta P_{e,o}}{P_{e,o}}\right)^2 + \left(\frac{\delta P_s}{P_s}\right)^2 + 0.2\left(\frac{\delta P_s}{P_s}\right)^2 + 0.2\left(\frac{\delta P_d}{P_d}\right)^2\right]^{\frac{1}{2}} \quad (5)$$

The temperature and pressure values of system are considered for 32 °C ambient temperature and 4 row condenser and given as

$T_{e,i}$ = -11±0.1$^0$C $\quad$ $T_{e,o}$ =-4.0+0.1$^0$C

$P_{e,i}$=4±1 psig

$P_{e,o}$=4.1±1 psig $\quad$ $P_s$= 4 ±1 psig

$P_d$ = 17.5 ± 1 psig

The values given above are substituted in the Equation 4.5.

$$\delta COP_{th} = \left[\left(\frac{0.1}{-11}\right)^2 + \left(\frac{0.1}{-4}\right)^2 + \left(\frac{1}{0.4}\right)^2 + \left(\frac{1}{0.41}\right)^2 + \left(\frac{1}{0.4}\right)^2 + 0.2\left(\frac{1}{0.4}\right)^2 + 0.2\left(\frac{1}{1.75}\right)^2\right]^{\frac{1}{2}}$$

$\delta COP_{th}$ = 0.02047 or 2.047 %

The value of $\delta COP_{th}$ shows the uncertainty value in theoretical calculations varying about 2.047% from the original value.

Theoretical COP with the uncertainty correction

$$= COP_{th} \pm (2.047/100) * COP_{th}$$

**Modelling and governing equations :**

Exergy or availability is a thermodynamic property that represents the maximum work that can be obtained from a fluid stream in a reversible process until it reaches the thermodynamic equilibrium with the surroundings. Exergy analysis can be used to evaluate the performance of thermodynamic system. Unlike energy, exergy is not conserved but it will be destroyed.

With the experimental data obtained from the tests, the exergy analysis is carried out to find exergy loss of the "three stage ARC system" in order to obtain a quantitative measurement of the system inefficiency. Under the assumption that the change of kinetic and potential energy is negligible and the ambient temperature is $T_0$, the exergy is given by the equation.

$$\psi = h - T_0 s \quad (6)$$

$$\psi = (h - h_0) - T_0 (s - s_0) \quad (7)$$

## ■ RESULTS AND DISCUSSION

The performance analysis of nano particle eco-friendly chilling plant for fish processing using R404a was performed. The system was charged at different composition for their corresponding compressors and before initiation they were checked for its correctness by digital physical balance with accuracy of 1 mg. The different combinational testing was executed and the observations were recorded and results were plotted as graphs and plots. The following are the interpretations and conclusions of the results of this experimental study.

Fig. 1 shows the variation of co-efficient of performance and compressor work input for different percentage of Nano particle ($Al_2O_3$). It is observed that the increase in COP is due to the excess energy stored inside the compressor reducing the unnecessary work for compression which reduces the work input to the compressor and increasing the refrigerating effect and thus the COP with the increase in percentage of nano particle during operation. Further the increase in percentage of nano particle into the system reduces the co-efficient of performance through utilizing more amount of work supplied rather in compression into increasing the output temperature instead of increasing the discharge pressure.

The maximum and minimum values of COP

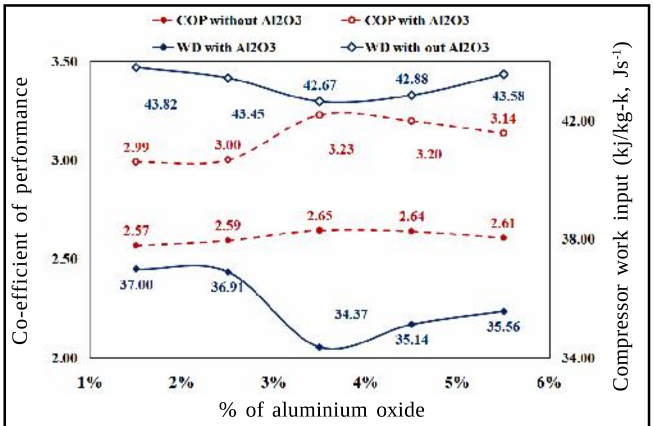


**Fig. 1 : Variation of co-efficient of performance and compressor work input for different percentage of nano particle ($Al_2O_3$)**

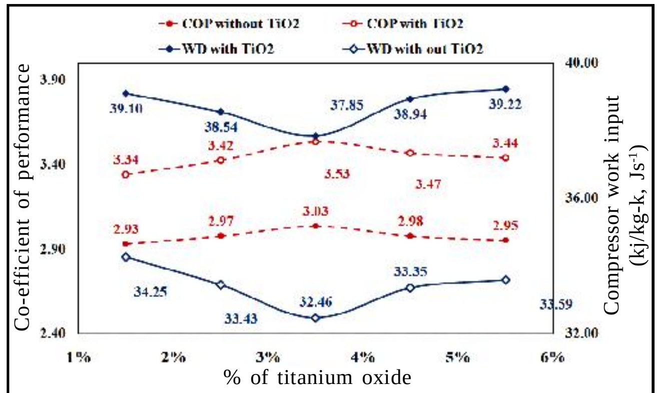


**Fig. 3 : Variation of co-efficient of performance and compressor work input for different percentage of Nano particle ($TiO_2$)**

observed were 2.65 and 2.57 for the mixture without $Al_2O_3$ and 3.23 and 2.99 for the mixture with $Al_2O_3$. Among which the maximum value lies for 3% of nano particle. The corresponding low values of work done noted were 42.67 and 43.82 kj/kg-K as well as 34.37 and 37 kj/kg-K. The high value of work input to the compressor yields low value of COP and vice versa. Lower the work input to the compressor and higher the COP being the best operating conditions of any refrigerating system, the recommended percentage of nano particle ($Al_2O_3$) as 3% when used along with R404a with 3.23 as COP and 34.37 kj/kg-K work input to the compressor. Fig. 2 and 3 explain the concepts for the nano particles CuO (3% with 3.97 as COP and 29.60 kj/kg-K work input to the compressor) and $TiO_2$ (3% with 3.53 as COP and 32.46 kj/kg-K work input to the compressor).

Fig. 4 shows the variation of co-efficient of performance and refrigerating effect for different percentage of nano particle ($Al_2O_3$). It is observed that the increase in COP is due to the excess energy stored inside the compressor reducing the unnecessary work for compression and thus saving the work required to achieve the same refrigerating effect as well as with high value of refrigerating effect and its corresponding work input yielding higher COP with the increase in percentage of nano particle during operation. Further the increase in percentage of nano particle into the system reduces the co-efficient of performance through utilizing more amount of work supplied rather in compression into increasing the output temperature instead of increasing the discharge pressure.

The maximum and minimum values of COP observed were 2.65 and 2.57 for the mixture without

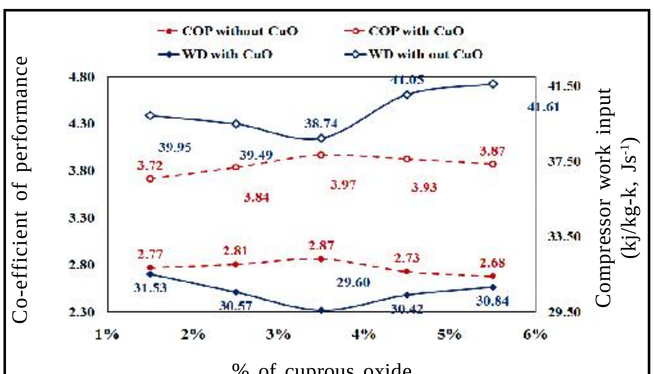


**Fig. 2 : Variation of co-efficient of performance and compressor work input for different percentage of nano particle (CuO)**

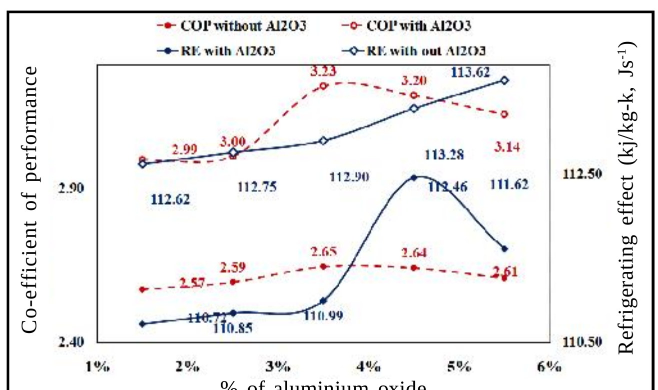


**Fig. 4 : Variation of co-efficient of performance and refrigerating effect for different percentage of nano particle ($Al_2O_3$)**

$Al_2O_3$ and 3.23 and 2.99 for the mixture with $Al_2O_3$. Among which the maximum value lies for 3% of nano particle. The corresponding values of refrigerating effects noted were 112.90 and 112.62 kj/kg-K as well as 110.99 and 110.72 kj/kg-K. The lower value of refrigerating effect yields low value of COP and vice versa. Lower the work input to the compressor, higher values of refrigerating effect and higher the COP being the best operating conditions of any refrigerating system, the recommended percentage of nano particle ($Al_2O_3$) as 3% when used along with R404a with 3.23 as COP and 34.37 kj/kg-K work input to the compressor as well as 110.99 kj/kg-K refrigerating effect.

Fig. 5 and 6 correspondingly explain the concepts with respect to the refrigerating effect as explained in the Fig. 2 (3% of CuO when used along with R404a with 3.97 as COP and 29.60 kj/kg-K work input to the compressor as well as 117.48 kj/kg-K refrigerating effect) and 5 (3% of $TiO_2$ when used along with R404a with 3.53 as COP and 32.46 kj/kg-K work input to the compressor as well as 114.88 kj/kg-K refrigerating effect).

Fig. 7 compares the effect of nano particles on COP, refrigerating effect and work input to the compressor with the refrigerant mixture R404a for without and with nano particles during operation. The trend of reduced work input and increased refrigerating effect compared with the system operation without nano particle and along with nano particle are shown in Fig 7. The maximum COP observed was 3.97 which correspond to 3% CuO which has 29.60 kj/kg-K compressor work input and 119.41 kj/kg-K refrigerating effect as well as increased COP as compared to the system without nano particle (CuO).

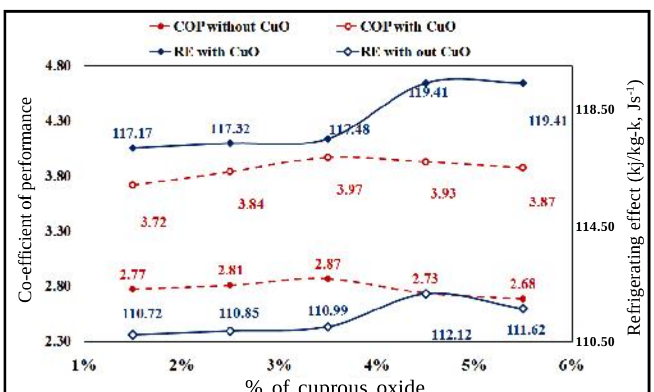


**Fig. 5 : Variation of co-efficient of performance and refrigerating effect for different percentage of nano particle (CuO)**

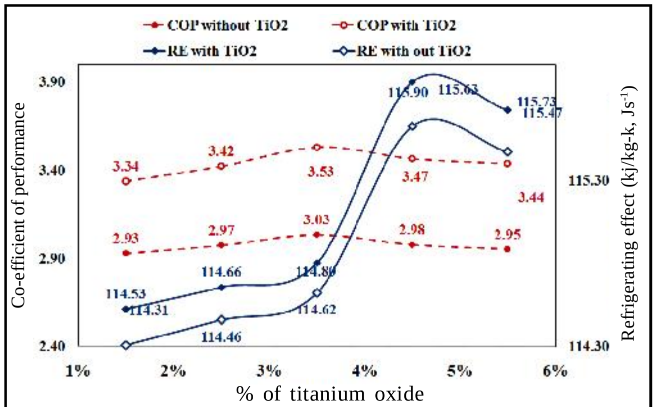


**Fig. 6 : Variation of co-efficient of performance and refrigerating effect for different percentage of nano particle ($TiO_2$)**

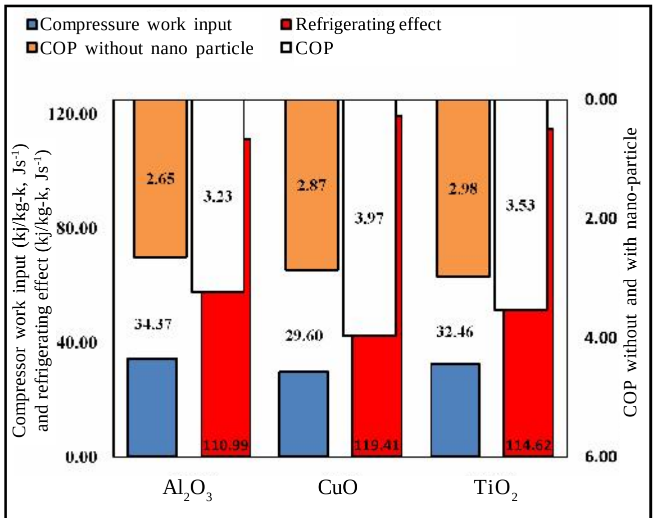


**Fig. 7 : Comparison of effect of nano particles on COP, refrigerating effect and work input to the compressor with the refrigerant mixture R404a**

Lesser the work input to the compressor, higher the refrigerating effect and better the COP being the expectations from the system it is obvious from the Fig. 4 and 5 that 3% of CuO yields very less work input (29.60 kj/kg-K) along with highest refrigerating effect (119.40 kj/kg-K) along with 3.97 as its corresponding COP and thus recommendations emulate the system working with R404a as refrigerant has to be loaded with 3% CuO nano particle for optimized performance. Thus the study recommends that the R404a along with 3% CuO nano particle can be used for the optimized operation of nano particle eco friendly chilling plant for fish processing.

## Conclusion :

Thermodynamic investigations on nano particle eco friendly chilling plant for fish processing aims at finding an alternative refrigerant mixture for CFC and HCFC refrigerants which fulfils the requirements of error free working of the system in the range of 264K (-11 $^oC$) taking care of environmental friendly, exergic and energy efficiency aspects during its life cycle.

The performance analysis was done on nano particle eco friendly chilling plant for fish processing using five combinations of nano particles for R404a. The best performance of the system was identified using the comparison of system parameters like COP, compressor work input, refrigerating effect, compressor suction and discharge pressure and temperature at all the state points of the system. Mind provoking findings that lead the recommendation is given for the reviewers as an essence of this experimental study.

Since the emphasis has been laid on COP and evaporating temperature not given primary importance and hence, the study concludes that the mixture of R404a offering the COP of 3.97 with 3% CuO having 29.6 kj/kg-K work input to the compressor along with highest refrigerating effect of 119.40 kj/kg-K can be used as an alternative refrigerant for nano particle eco friendly chilling plant for fish processing at the temperature range of -11$^o$C.

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## REFERENCES

**Anand, S. and Tyagi, S.K. (2012).** Exergy analysis and experimental study of a vapour compression refrigeration cycle. *J. Thermal Analysis & Calorimetry*, **110** : 961-971.

**Andrey Rozhentsev and Vjacheslav Naer (2009).** Investigation of the Starting modes of the low-temperature refrigerating machines working on the mixtures of refrigerants. *Internat. J. Refrigeration*, **32** : 901-910.

**Bansal, Pradeep, Vineyard, Edward and Abdelaziz, Omar (2012).** Status of not-in-kind refrigeration technologies for household space conditioning, water heating and food refrigeration. *Internat. J. Sustain. Built Environ.*, **1** : 85-101.

**Boissieux, X., Heikal, M.R. and Johns, R.A. (2000).** Two-phase heat transfer co-efficients of three HFC refrigerants inside a horizontal smooth tube, part II: Condensation. *Internat. J. Refrigeration*, **23** : 345-352.

**Chen, Jianyong and Yu, Jianlin (2008).** Performance of a new refrigeration cycle using refrigerant mixture R32/R134a for residential air-conditioner applications. *Energy & Buildings*, **40** : 2022-2027.

**Cleland, D.J., Keedwell, R.W. and Adams, S.R. (2009).** Use of hydrocarbons as drop-in replacements for HCFC-22 in on-farm milk cooling equipment. *Internat. J. Refrigeration*, **32** : 1403-1411.

**Fernando, Primal, Bjorn Palm, Per Lundqvist and Eric Granryd (2004).** Propane heat pump with low refrigerant charge: Design and laboratory tests. *Internat. J. Refrigeration*, **27** : 761-773.

**Gao, Zanjun, Xu, Yingjie, Li, Peng, Cui, Xiaolong, Han, Xiaohong, Wang, Qin and Chen, Guangming (2012).** Solubility of refrigerant trifluoromethane in N,N-dimethyl formamide in the temperature range from 283.15 K to 363.15 K, *Internat. J. Refrigeration*, **35** : 1372-1376.

**Jung, Dongsoo, Kim, Chong-Bo, Song, Kilhong and Park, Byoungjin (2000).** Testing of propane/isobutane mixture in domestic refrigerators. *Internat. J. Refrigeration*, **23** : 517-527.

**Lee, D.Y., Ahn, Y., Kim, Y., Kim, Y., Chang, Y.S. and Nam, L. (2002).** Experimental Investigation on the drop-in performance of R407C as a substitute for R22 in a screw Chiller with shell-and-tube heat exchangers. *Internat. J. Refrigeration*, **25** : 575-585.

**Lee, J.H., Bae, S.W., Bang, K.H. and Kim, M.H. (2002).** Experimental and numerical research on condenser performance for R-22 and R-407C refrigerants. *Internat. J. Refrigeration*, **25** : 372-3 82.

**Michael Uhlmann and Stefan S. Bertsch (2012).** Theoretical and experimental investigation of start-up and shutdown behavior of residential heat pumps. *Internat. J. Refrigeration*, **35** : 2138-2149.

**Park, Ki-Jung and Jung, Dongsoo (2009).** Performance of heat pumps charged with R170/R290 mixture. *Appl. Energy*, **86** : 2598-2603.

**Wang, Ruixiang, Wu, Qingping and Wu, Yezheng (2012).** Use of nano particles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants. *Energy & Buildings*, **42** : 2111-2117.