Project Report

on

Nano particle assisted VCR System: An investigation to enhance the performance of the VCR system

Submitted By

Mr. Om Trivedi
(21MMT001)

Under the Guidance of

Dr. Vivek Patel
Associate Professor, PDEU

Dr. Jatin Patel
Associate Professor, PDEU

Prof. Anurag Mudgal
Professor, PDEU

Department of Mechanical Engineering,
School of Technology (SOT)
PANDIT DEENDAYAL ENERGY UNIVERSITY
(Formally known as PDPU), Gandhinagar – 382007

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Indian Society of Heating, Refrigerating and Air-conditioning Engineers (ISHRAE) headquarters, New Delhi

Certificate

*This is to certify that the project report entitled "**Nano particle assisted VCR System: An investigation to enhance the performance of the VCR system”** submitted by **Om Trivedi (20MMT001, ISHRAE Member ship No. S22107247)** is the record of work carried out by him under our supervision and guidance **(supported by ISHRAE HQ, New Delhi through ISHRAE Ahmedabad chapter).***

Project Guide

Dr. Vivek K. Patel
Associate Professor,
Mechanical Engineering Department,
Pandit Deendayal Energy University,

Project Co-Guide

Dr. Jatin Patel
Associate Professor,
Mechanical Engineering Department,
Pandit Deendayal Energy University

Prof. Anurag Mudgal
Professor,
Mechanical Engineering Department
Pandit Deendayal Energy University

Acknowledgement

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Yours Sincerely,

Om Trivedi

Abstract

The demand for energy-efficient and environmentally friendly refrigeration systems has driven the development of novel technologies in the field of cooling and refrigeration. The VCR system is a fundamental technology in the field of refrigeration and air conditioning, widely used in various applications ranging from residential to industrial refrigeration. The VCR system is known for its high efficiency and versatility, but there is a continuous quest for further improvement in its performance. The integration of nanoparticles in the VCR system offers a promising approach to enhance its efficiency and overall performance. Nanoparticles exhibit unique thermal properties and characteristics that can significantly improve heat transfer processes within the refrigeration cycle. By dispersing nanoparticles within the refrigerant, the VCR system can achieve better heat absorption and rejection, leading to improved overall energy efficiency. The nanoparticle-based VCR system employs nanoparticles with tailored properties to enhance heat transfer. These nanoparticles can be functionalized to have high thermal conductivity, allowing for efficient heat transfer between the refrigerant and the cooling medium. Additionally, the nanoparticles can alter the refrigerant's phase-change behavior, enabling more efficient evaporation and condensation processes during the cooling cycle.

The incorporation of nanoparticles in the VCR system requires careful consideration of various factors, such as nanoparticle concentration, stability, and compatibility with the refrigerant. The nanoparticle-based VCR system offers several potential benefits. It can significantly enhance the energy efficiency of the system, resulting in reduced electricity consumption and operating costs. Additionally, improved heat transfer properties enable more compact and lightweight system designs, making it suitable for various applications with space limitations.

In the present work, VCR system with Al_2O_3 nano particle are investigated and its performance are compared with normal VCR system. Design of experiment is implemented to decide the number of experiments. Based on which 18 different experiments are executed. Two different concentration (1% and 2%) of nano particle are investigated with coil type and cooling tower type condenser. Effect of different water flow rate and air flow rate is also investigate. The comparative results are presented in the form of cooling effect, power consumption and COP of the system.

Keywords: Nano Particle, VCR System, Design of experiments, Power consumption, COP

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Chapter 1

Detailed Information of Grant Fetchers

1.1 Local Chapter Name

ISHRAE – Ahmedabad Chapter;
204, Sarita Complex,
Behind Samudra Complex,
Off. C.G. Road, Navrangpura,
Ahmedabad, Gujarat - 380009
Tel.:079-26400711
E-Mail: ishraeahd@gmail.com

1.2 Institute Name and Address

Pandit Deendayal Energy University (Formally known as PDPU),
Raisan, Gandhinagar, Gujarat 382007,
Tel.: 079-23275403
E-Mail: mehod@sot.pdpu.ac.in

1.3 Project Title, Reference Number and Amount sanctioned

Project Title: Nano particle assisted VCR System: An investigation to enhance the performance of the VCR system

Project reference No.: SRPG PG 12

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1.4 Student Name

Mr. OM Trivedi
M. Tech- Thermal Engineering,
(ISHRAE Membership No: S22107247)
Contact No: +91 9638818255, E-mail: om.tmtmt21@sot.pdpu.ac.in

1.5 Project Guides

Guide:

Dr. Vivek K. Patel
Associate Professor,
Mechanical Engineering Department,
School of Technology,
Pandit Deendayal Energy University,
Raisan, Gandhinagar-382426
(M) 9427259895,
Email ID: VivekP@sot.pdpu.ac.in

Co-Guide;

Dr. Jatin Patel
Associate Professor,
Mechanical Engineering Department,
School of Technology,
Pandit Deendayal Energy University,
Raisan, Gandhinagar-382426
(M) 9428415422,
Email ID: Jatin.Patel@spt.pdpu.ac.in

Prof. Anurag Midgal
Professor,
Mechanical Engineering Department,
School of Technology,
Pandit Deendayal Energy University,
Raisan, Gandhinagar-382426
(M) 9428415422,
Email ID: anurag.mudgal@spt.pdpu.ac.in

1.6 Approved Objectives of the Project

- To design and develop the nano particle assisted vapour compression refrigeration system
- Identify the effect of nano refrigerant on the cooling effect and power consumption
- To investigate the performance of the proposed system in terms of COP and compare the system performance with traditional VCR system

1.7 Methodology

The methodology adopted in the proposed work of development and investigation of nano particle assisted VCR system is shown in below Fig. 1:

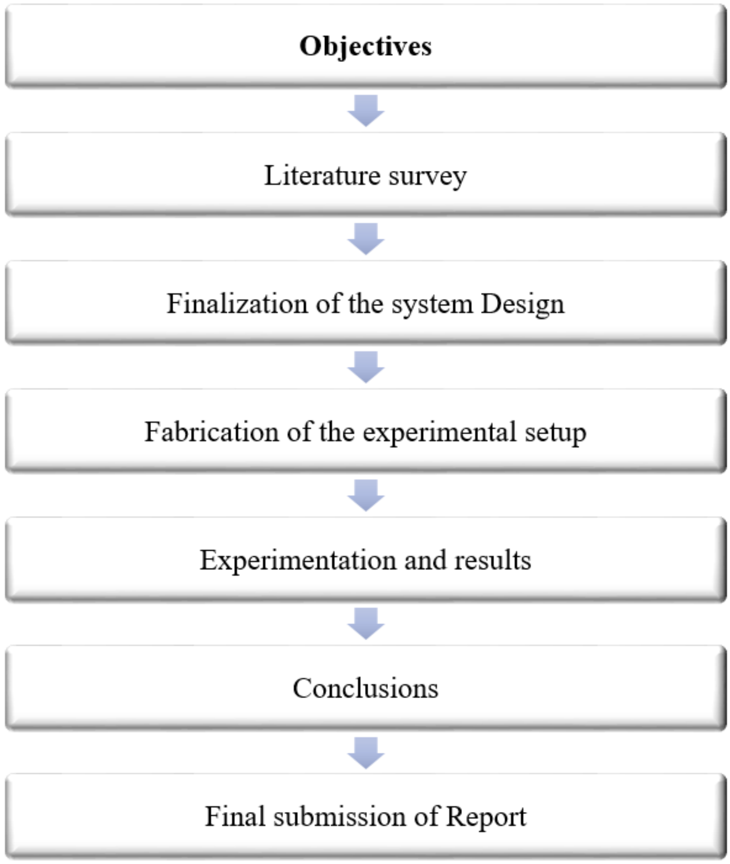

Fig. 1: Methodology of the proposed work

Chapter 2
Project Summary

2.1 Introduction and Literature Survey

Today the world is confronted with the challenge of energy security with the governments of many nations implementing energy policies on the use of energy to decrease energy consumption levels for long term sustainability. Government leaders and researchers have deliberated the problem of growth in energy consumption because the current generation of energy accompanies the burning of fossil fuels, which contributes to global warming. It is estimated that about 50% of energy consumption in commercial buildings goes to heating, ventilation and air-conditioning (HVAC) systems. Therefore, researchers are now focused on energy consumed by refrigeration and air-conditioning system. Refrigeration and air-conditioning are needed for domestic and industrial comfort and preservation purposes. Refrigeration, air conditioning and heat pump appliances require significant amounts of energy for their operation. Due to this energy challenge, researchers are finding various means to improve performance and energy efficiency of refrigeration and air conditioning system.

Recently researchers adopted the use of nano particle for the performance improvement of refrigeration system. The purpose of using nano particle assisted refrigerant in place of conventional refrigerant in any refrigeration system is to make it energy efficient and compact. The refrigeration systems working on nano particle assisted refrigerants are likely to have its improved cooling capacity. These refrigeration systems consume less power, and hence are more energy efficient. This is due to the fact that nano particle possess superior thermo physical properties in comparison to the conventional or base refrigerants. Nanoparticle applications have captured the attention of the innovative world due to their special properties and ability to enhance the properties of working fluids. Nano particles are considered as an advanced class of fluids with particle size 1–100 nm suspended in base fluids. Such suspensions form the two-phase system, in which the solid phase is dispersed in the liquid phase. Nanoparticles are generally of metals, non-metals, or their oxides, which possess the potential to improve and influence the conduction and convection thermal performance of the base fluids.

Various researchers worked on nano particle assisted VCR cycle. The studies reported for nano particle based VCR system are reviewed and consolidated in Table 01.

Table 01: Nano Particle based VCR System review

Researcher	System	Type of study	Base fluid	Nano-particle	Key findings
Kundan and Singh [1]	Vapour-compression refrigeration system	Experimental	R134a	0.5 and 1 wt% of Al_2O_3	COP improved by 16.34%.
Talpada & Ramana [2]	Single-effect absorption refrigeration system	Experimental	$LiBr/H_2O$	0.05 wt% of Al_2O_3	Maximum improvement in COP was 15% with 0.05 wt% of Al_2O_3 nanoparticles.
Hussain et al.[3]	Vapour-compression refrigeration system	Experimental	R134a	0.01, 0.005 and 0.001 wt% of Al_2O_3	COP enhanced by 25.7%, 17.46% and 11.74% for 0.01%, 0.005% and 0.001% wt. of Al_2O_3, respectively at an ambient temperature of 28°C.
Rahman et al.[4]	Vapour-compression refrigeration system	Experimental	R407c	5 vol% of Al_2O_3	COP improved by 4.59%.
Kumar et al. [5]	Vapour-compression refrigeration system	Theoretical	R134a and R152a	0.01 and 0.06 wt % of ZrO_2	COP improved by 33.45% with 0.06 vol% of ZrO_2 to R152a.
Harichandran et al. [6]	Vapour-compression refrigeration system	Experimental	R134a	3 vol % hexagonal boron nitride (h-BN)	60% improvement in the energy saving as compared to base POE oil system
Aktemur and Öztürk [7]	Vapour-compression refrigeration system	Experimental	R1270	Cuo with 0.05-0.3 vol %	21.23% lower total exergy destruction and 29.32% higher COP of the system
Ajayi et al. [8]	Vapour-compression refrigeration system	Experimental	R134a	Aluminum based 0.1-0.3 vol %	Improvement in cooling capacity and energy consumption

Ajula et al. [9]	Vapour-compression refrigeration system	Experimental	R600a and R290	0.05-01 vol% TiO_2	5-7% improvement in energy and exergy performance
Bi et al. [10]	Vapour-compression refrigeration system	Experimental	R600a	0.5 g/L TiO_2	9.6% reduction in energy consumption
Babaei et al. [11]	Hybrid absorption/ recompression refrigeration cycle	Theoretical	$LiBr/H_2O$	5 vol% of Fe, Al_2O_3 and SiO_2	Maximum improvement in COP was 14.6% with 5 vol% of Fe.
Jiang et al. [12]	Single-effect absorption refrigeration system	Experimental	NH_3/H_2O	0.5 wt% of TiO_2	COP improved by about 27%
Jin et al. [13]	Single-effect absorption refrigeration system	Experimental	NH3-$LiBr/H_2O$	0.1–0.5 wt% of TiO_2	Maximum improvement in COP was 18.96%
Ande et al. [14]	Vapour-compression refrigeration system	Experimental	R134a	1.6 wt% of CuO	COP improved by 16.66%, and energy consumption reduced by 13.79%.
Aktas et al. [15]	Vapour-compression refrigeration system	Theoretical	R22, R134a, R430A, R600a & R436A	0.0006 wt% of Al_2O_3	Maximum improvement in COP achieved with the use of R600a/Al_2O_3.
Selimefendigil and Bingolbali [16]	Vapour-compression refrigeration system	Experimental	R134a	0.5 and 1 vol% of ZrO_{2a}	COP improved by 21.42% with 1 vol% of ZrO_2.

2.2 Design/Modelling of System

To initiate the research associated with the performance enhancement of nano particle assisted VCR system, the detail design of each component is carried out. Following assumptions are considered for design/experimentation of the proposed system

2.2.1 Assumptions

To simplify the design/modelling of system, several assumptions are made as follows:

- Steady state operation of all system components.
- Evaporator and condenser exit states are saturated.
- Refrigerant and solution expansion valves are properly insulated therefore isenthalpic.
- Pressure drop in connecting pipes and expansion valve heat loss are neglected.

2.2.2 VCR System Modelling

Evaporator of VCR cycle extracts heat from air stream and its temperature (T_{evap}) in kept at 5 °C. As heat is exchanged between air and R134a refrigerant, the heat transfer rate in evaporator is (Fig. 02)

$$\dot{Q}_{evap} = \dot{m}_{air} (h_{a2} - h_{a3}) \quad (1)$$

The air enthalpy difference ($h_{a2} - h_{a3}$) is given by

$$h_{a2} - h_{a3} = [(Cp_a + Cp_v\omega_{a2})T_{a2} - (Cp_a + Cp_v\omega_{a3})T_{a3}] + h_{fg,w}(\omega_{a3} - \omega_{a3}) \quad (2)$$

In expansion valve,

$$h_{r4} = h_{r3} = h_{sat}@(T_{cond}) \quad (3)$$

The cooling effect observed in evaporator is given as:

$$\dot{Q}_{evap} = \dot{m}_{ref}(h_{r1} - h_{r4}) \quad (4)$$

The condenser heat transfer rate ($\dot{Q}_{cond}$) is given by:

$$\dot{Q}_{cond} = \dot{m}_{ref} (h_{r2} - h_{r3}) \quad (5)$$

The work transfer (power consuming) devices in this system are: A compressor, two air blowers, a pump and an air heater (Fig. 2). The compressor work is given by:

$$\dot{W}_{comp} = \dot{m}_{ref} (h_{r2} - h_{r1}) \quad (5)$$

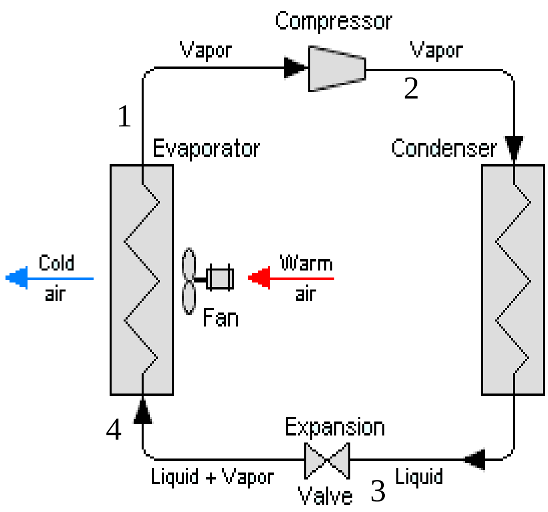

Fig. 2: VCR system schematic arrangement

The detail specification of each of the components used in the proposed design is given in Table 2.

Table 2: **Specification of VCR system**

Component	Type	Parameter	Value
Compressor	Hermetically sealed	Capacity	3600 W (1 TR)
		Refrigerant used	R134a
Condenser	Submerge Coil type	Material	Copper
		Outside diameter	240
		Inside diameter	220
	Cooling tower type	Material	Copper
		Outside diameter	240
		Inside diameter	220
Expansion valve	Flare Connection Type	Maximum Operating Pressure	0 – 39 bar
Evaporator	Fin & Tube Type	Material	Copper & GI
		Dimensions	14” x 14” x 4”
		Area	0.127 m^2

Further, the CAD model of the proposed set-up is developed in SOLIDWORKS solid modelling tool and shown in Fig. 3. The computer-aided designing of the setup is done as it helps in (a) deciding the dimensions and materials of the sheet covers for enclosing the components and of the square stand piping (b) for customizing the placement arrangement of all components to occupy the minimum space and to maintain the centre of gravity.

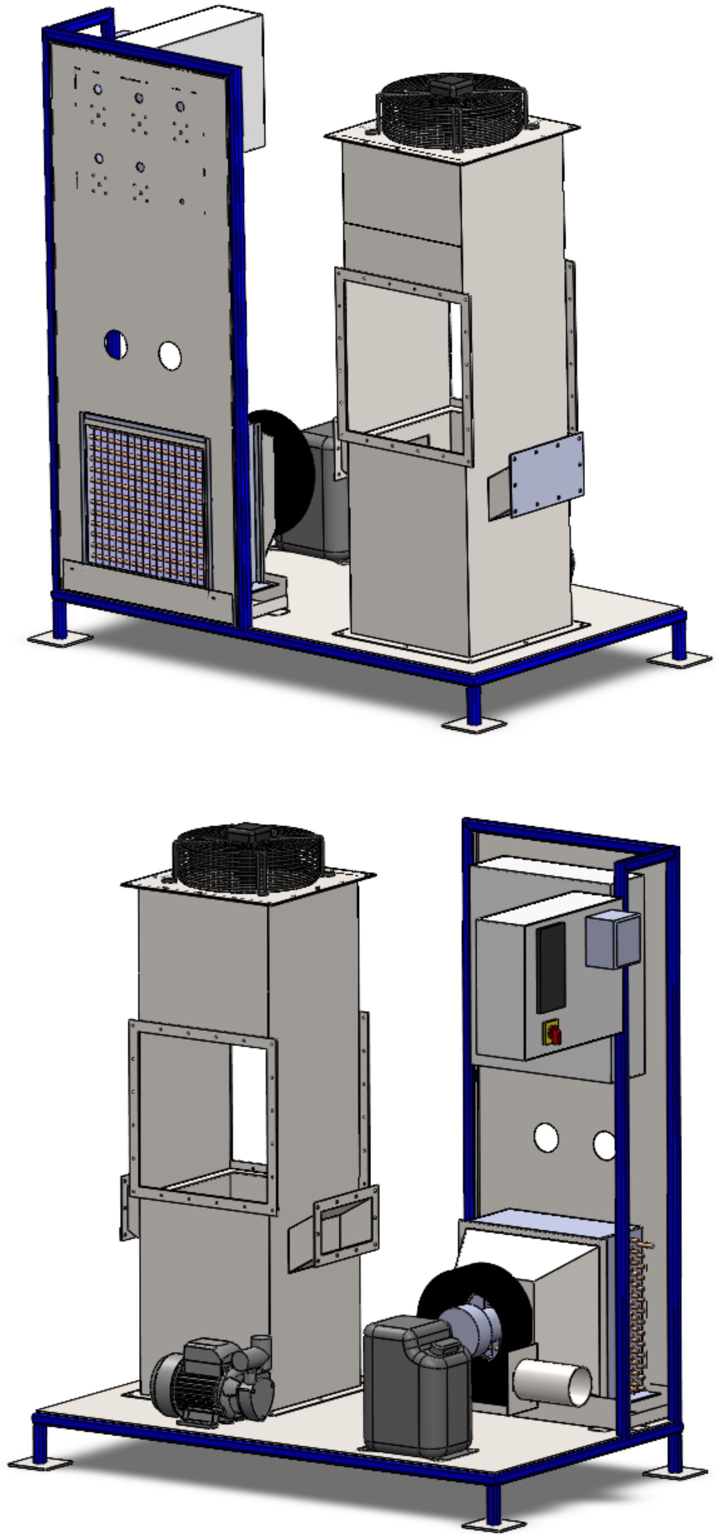

Fig. 3: Orthogonal view of the proposed system

2.3 Experimental Investigation

This section describes the experimental investigation being carried out with a nano-particle based VCR system. This includes the detailing of the experimental setup and its components along with the measurement provisions made. Also, the description of the technique employed for the design of experiments.

2.3.1 Experimental Setup Description

The schematic diagram of the experimental setup developed is shown in Fig. 4 while the actual experimental setup developed is shown in Fig. 5. A R134-a driven VCR unit of 1 TR is selected which consists of a sealed compressor (1 TR), a fin and tube type evaporator, water cooled condenser and capillary tubing for the expansion. The provision is given in the compressor to charge/discharge the nano particles along with the refrigerants. The known quantity of any nano particle (either by %vol or % weight concentration) can be charge from this connection before the experimentation.

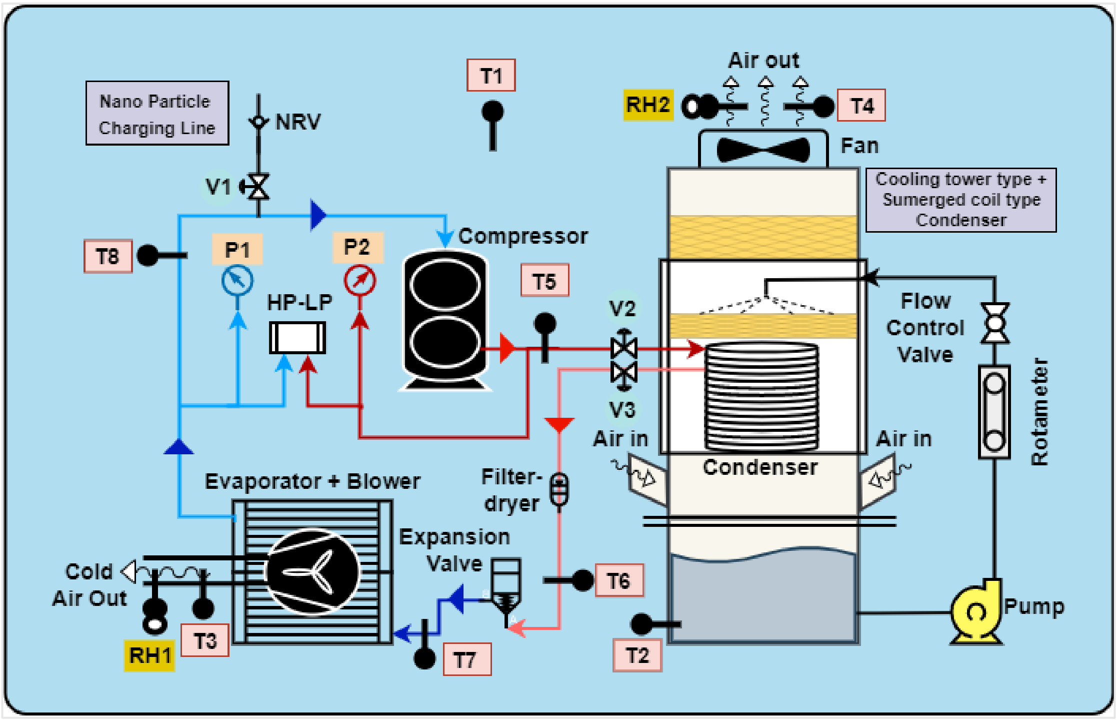

Fig. 4: Schematic diagram of the experimental setup

Fig. 5: The experimental setup of the system

The two different type of condenser is employed in the proposed setup; Submerge coil type condenser, and Cooling tower type condenser. In addition to that provision is given in the experimental setup to change other type of condenser also. For the water flow control in the condenser, manual valve provision is provided. Water flow is indicated in the rotameter.

On the evaporator side, air flow can be controlled by varying the blower speed using a regulator (a centrifugal blower of (400 W) are used). All data of temperature, humidity, ppower consumption, control temperature etc. are shown in the panel box. Also, the suction and discharge pressure of the refrigeration cycle is shown in the pressure gauges provided below the panel. In addition to that HP-LP cutout is used for system safety.

2.3.2 Measurement Provisions

The parameters to be measured are temperature, humidity, water flow rate, air flow rate and energy consumption data. The temperature and RH sensors are placed at the required locations. To measure the air flow rate at the exit, digital anemometer is to be used. For the water flow measurement rotameter is used. All the electrical connections (power) are made to a single switching and control panel. This control panel has an energy meter which can read the load (in kW) being consumed at any instant of time. The image of control panel for measurement is shown in Fig. 6 while specifications of the measuring devices used is given in Table 3.

Fig. 6. Control panel for measuring instruments

Table 3: Measuring instruments specifications

Instrument	Specifications
Temperature sensor	▪ RTD Pt-100 Temp. sensors ▪ Range of measurement: -50 °C to 200 °C. ▪ Accuracy of measurement: ± 1 °C
Relative Humidity Sensor	▪ Range of measurement: 0 % to 100 %. ▪ Resolution: 0.1 %. ▪ Accuracy of measurement: ± 1 %.
Rotameter	▪ Range of measurement: 400 – 4000 LPH
Anemometer	▪ HTC AVM-06. ▪ Air velocity range: 0.8 to 30 m/s. ▪ Resolution: 0.01 m/s. ▪ Accuracy of measurement: ± 2 % of reading.

2.3.3 Scope and Objectives of the Experiments

A small-scaled experimental setup of nano particle assisted VCR system with is fabricated and all the experiments are performed with the setup. The scopes of the experimentation with the developed setup are:

- Different concentration of nano particle is charged in the VCR system to measure the performance if the system.
- The condenser section are made flexible to test different types of condenser with different water flow rate.
- Energy saving analysis and COP measurement of nano particle assisted VCR system by comparing its performance with conventional VCR.
- Effect of condenser water flow rate and evaporator air flow rate can be investigated.
- Modifications of the setup to identify the effect of nano fluid on waterside/air side can be done in future.

Based on the setup scopes, the specific objectives made for experimentation are:

- To study the effect of nano refrigerant on the cooling effect and power consumption
- To study the performance of the proposed system in terms of COP and compare the system performance with traditional VCR system

2.4 Design of Experiments

Experiments enable us to interpret the system behaviour from the data recorded by noting the response parameters (outputs) against variation allowed in the input variables [17]. We aim for the maximum information extraction (of system behaviour) with minimum number of experimental runs. For this to achieve, experiments are designed using various techniques like factorial design, Taguchi design, central composite design etc. [17]. DOE is a statistical methodology adopted for investigating the system input-output behaviour with optimized number of experimental runs from all possible combinations. This is employed to minimize the time required and hence the money power required for the experimentation in case when you have larger number of influencing input parameters to explore and the interaction effect of the factors is significant. The inputs are known as the “factors” while its values within its feasible range (available for the experimentation) selected are called as the “levels” in the language of DOE. The output parameters are usually called as “responses” [17]. A regression model is generated post experimentation which contains a mathematical expression that best fits the system responses with the factors. The statistical software which are widely used for DOE are

MINITAB, Design Expert, Fusion Pro etc. MINITAB software is used for the DOE in present work. The 3 variables (factors) selected for this purpose are [a] air mass flow rate, ($\dot{m}_{air}$) [b] water flow rate inlet temperature, (m_{water}) [c] nano particle concentration, (X_1). The levels of these 3 factors are given in Table 4.

Table 4: Levels of selected DOE variables

	Levels		
	1	2	3
Air flow rate $\dot{m}_{air}$, (CFM)	250	300	350
Water flow rate $\dot{m}_{water}$, (LPM)	15	20	25
Nano fluid concentration X_1 (% wt),	0	1	2

Also, both the condenser (i.e. submerge coil type and cooling tower type) are experimented in the investigation. The concentration on nano particle was selected according to the feasibility of the experimentation. From this Factors and levels, Taguchi L18 Orthogonal array is selected for DOE. Total 18 numbers of experiments were performed as suggested by applying L18 array. The various combinations for all 18 experiments are shown in the Table 5.

Table 5: L18 Orthogonal Array

Sr. No.	Condense Type	Air flow (CFM)	Water Flow (LPM)	Nano –Particle concentration (%)
1	Cooling -Tower	250	15	0
2	Cooling -Tower	300	15	1
3	Cooling -Tower	350	15	2
4	Cooling -Tower	250	20	0
5	Cooling -Tower	300	20	1
6	Cooling -Tower	350	20	2
7	Cooling -Tower	250	25	1
8	Cooling -Tower	300	25	2
9	Cooling -Tower	350	25	0
10	Submerge coil	250	15	2
11	Submerge coil	300	15	0

12	Submerge coil	350	15	1
13	Submerge coil	250	20	1
14	Submerge coil	300	20	2
15	Submerge coil	350	20	0
16	Submerge coil	250	25	2
17	Submerge coil	300	25	0
18	Submerge coil	350	25	1

According to the scopes of the developed setup, the responses (performance measures) selected for the evaluation are:

a) Energy saving (i.e. reduction in compressor work)

$$\dot{E}_{saving} = (\dot{W}_{Comp})_{nano-assisted\ VCR} - (\dot{W}_{Comp})_{cnventional\ VCR} \quad (7)$$

Where, compressor work is given by

$$\dot{W}_{comp} = \dot{m}_{ref}\ (h_{r2} - h_{r1}) \quad (8)$$

b) Rise in cooling effect:

$$(\dot{Q}_{evap})_{rise} = (\dot{Q}_{evap})_{nano-assisted\ VCR} - (\dot{Q}_{evap})_{Conventional\ VCR} \quad (9)$$

Where, cooling effect is given by

$$\dot{Q}_{evap} = \dot{m}_{air}\ (h_{a2} - h_{a3}) \quad (10)$$

c) Increment in Co-efficient of performance (COP)

$$(COP)_{rise} = (COP)_{nano-assisted\ VCR} - (COP)_{Conventional\ VCR} \quad (11)$$

Where COP is given by

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \quad (12)$$

2.5 Results and Discussion

This section discusses the results obtained from the designed experimentation carried out with the developed setup. The number of experimentation is decided by implementing design of experiments (DOE). After performing the design experiments, comparative resulted are presented to evaluate the effect of nano fluid on the performance of VCR system. Finally, the effect of individual factor on the response parameter is also discussed.

2.5.1 DOE Results

The experiments were conducted as per the design suggested by Taguchi technique at the fixed ambient conditions. The measurement of all the temperature, pressure and relative humidity for all the 18 experiments are presented in Table 6.

Table 6: Temperature, pressure and RH measurement during experimentation

Sr No	P_1 (Psi)	P_2 (Psi)	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	RH_1 (%)	RH_2 (%)	Envi. RH (%)
1	39	185	31.6	40.5	16.6	33.6	77	36.2	7.2	18.4	85.8	95.1	58.5
2	36	175	32.1	41.2	18.1	32.7	80.2	35.4	7.9	19.8	82.8	94.8	56.8
3	34	165	32.5	40.1	21.1	33.5	81.5	35.8	11.3	23.9	83.7	95	58.1
4	40	180	32.2	43	17.4	34.2	84.7	36	6.8	20.4	81.1	94.8	60.2
5	35	178	31.8	42.5	18.9	34.8	83.5	35.2	7.6	22.1	81.9	95.5	59.5
6	40	176	31.9	42	21	33.7	82	35	11.4	24.2	80.3	95.9	58.6
7	34	170	32.5	44.2	17	34.1	80.7	35.7	6.5	21.5	81.6	96	57.5
8	35	169	31.5	42.5	18.1	32.7	86.2	35.1	8	21.8	83.5	96.1	59.5
9	46	200	32.7	45.6	21.8	35.3	85.4	39.7	12.1	25	81.2	95.6	59.3
10	35	169	32.8	44.8	17.2	34.5	81	37	6.6	21	85.2	92	57.6
11	43	200	32.1	45.3	18.5	32.6	76.6	39.1	8.5	20.1	83.5	93.7	59.1
12	39	178	31.8	45.8	21.1	32.5	79.5	37.9	11.5	23.1	84.2	92.8	58.6
13	36	175	32.4	45.2	17.1	33.5	78.5	37.8	6.8	19.8	84.8	93.4	59.2
14	34	176	32.4	44	17.5	31.8	77.6	36.6	7.5	19.9	82.4	93.7	60.2
15	44	180	31.5	45	21.8	31.6	75.9	40.3	12.2	24.1	82.5	93.1	60.8
16	35	172	32	44.8	16.9	32	75.8	37	6.9	19.2	83.7	91	61.8
17	42	190	32.1	44.9	18.4	32.4	76.3	39.2	8.3	20.3	83.1	94	61
18	40	175	31.6	44.2	21.3	32.8	78.4	37.5	11.8	23.3	81	92.5	58.6

Three responses (discussed in section 2.4) were noted for all 18 experimental runs. The response parameters are presented in the Table 7. The experimental results are having significant change in the responses for different combinations of runs. Based on the results, it is observed that higher nano fluid concentration in the VCR system result in higher COP of the proposed system as compared to conventional system.

Table 7: Response measures obtained during experiment

Sr No	Condenser Type	Air flow (CFM)	Water flow (LPM)	Nano particle concentration	Cooling Effect (kW)	Power (kW)	COP
1	Cooling - Tower	250	15	0	2.60	1.95	1.33
2	Cooling - Tower	300	15	1	2.91	1.9	1.53
3	Cooling - Tower	350	15	2	2.77	1.75	1.58
4	Cooling - Tower	250	20	0	2.57	2.01	1.28
5	Cooling - Tower	300	20	1	2.68	1.85	1.45
6	Cooling - Tower	350	20	2	2.65	1.7	1.56
7	Cooling - Tower	250	25	1	2.69	1.81	1.49
8	Cooling - Tower	300	25	2	2.79	1.65	1.69
9	Cooling - Tower	350	25	0	2.65	2.24	1.18
10	Submerge coil	250	15	2	2.71	1.64	1.66
11	Submerge coil	300	15	0	2.83	1.9	1.49
12	Submerge coil	350	15	1	2.60	1.87	1.39
13	Submerge coil	250	20	1	2.65	1.79	1.48
14	**Submerge coil**	**300**	**20**	**2**	**3.10**	**1.63**	**1.88**
15	Submerge coil	350	20	0	2.36	2.1	1.12
16	Submerge coil	250	25	2	2.62	1.69	1.55
17	Submerge coil	300	20	0	2.85	1.97	1.45
18	Submerge coil	350	25	1	2.50	1.8	1.39

It can be observed from the results that with addition of nano fluid the cooling effect is increases while the compressor power is reduces. As mentioned previously this behaviour is due to higher heat transfer rate in the presence of nano fluid. The results shows that the maximum cooling effect take places when the nano fluid concentration is 2% by weight. Further, the submerge coil type water cooled condenser is more effective as compared to cooling tower type condenser. One can observed from the results that 8.7% rise in cooling effect with 17.2% reduction in compressor work is observed in the proposed system as compared to convention VCR system (i.e without nano fluid). So, overall 22.8% rise in COP is observed in the proposed system as compared to convention VCR system for the same input parameters.

2.5.2 Effect of DOE Variables

Continuing the experimental investigation, the effect of factors (i.e. air flow rate, water flow rate and nano fluid concentration) and their interaction on the responses (i.e. cooling effect, compressor work, and COP of the system) are studied as it helps in knowing the dominating influencing parameters. Fig. 7 shows the main variables (individual) effect on the response (i.e. COP). It is observable from Fig. 7 that strict trend can be seen between the response and all 3 variables within their ranges. With increasing in the nano fluid concentration, the COP is increases. However, the COP is increases with increase in air flow rate up to certain extent. Further increase in air flow rate decreases the COP of the proposed system. Similarly, the COP of the proposed system reduces with the rise in condenser water flow rate up to certain extent afterwards COP became less or more constant. Thus the nano fluid concentration is found to be the dominating input variable that influences the response compared to the rest two variables as it has larger minimum-maximum span of the COP.

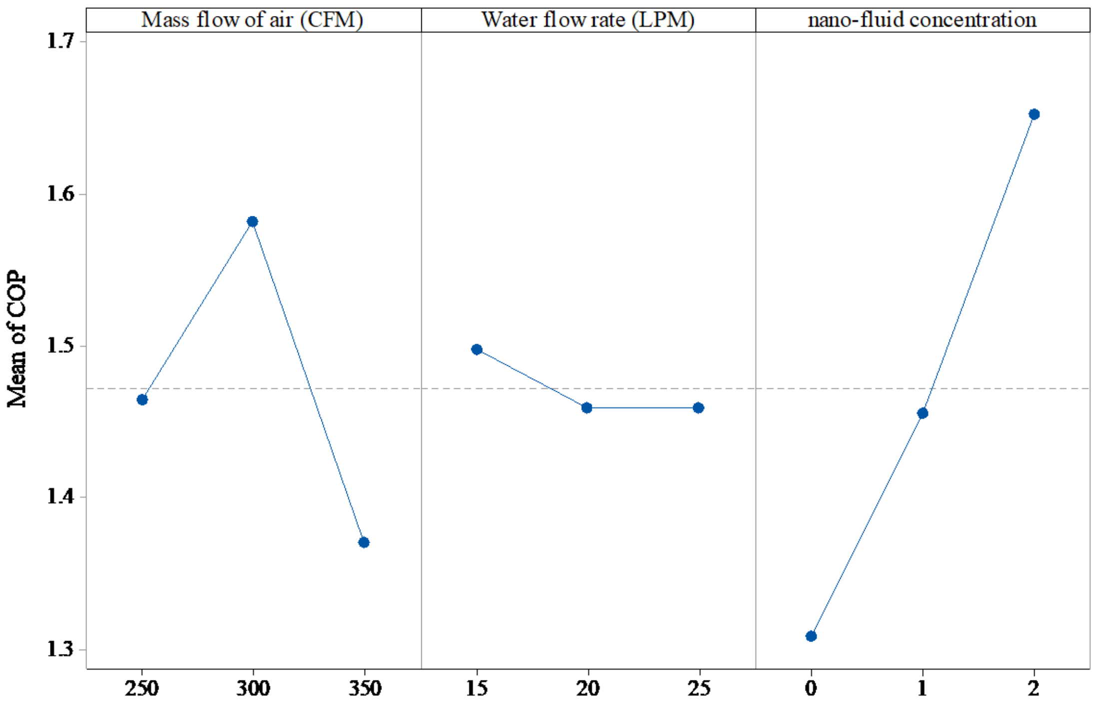

Fig. 7: Main effects plot for COP

2.6 Conclusion

This work investigates a nano particle assisted VCR system to identify the performance improvement over conventional VCR system. The experimental setup is developed with the provision of charging and discharging of nano particle along with refrigerant. The Al_2O_3 nano particle is investigated experimentally with VCR system. Two different concentration (1% and 2% by weight) of Al_2O_3 nano particle are investigated with the developed setup. The effect of evaporator air flow rate and condenser water flow rate is also investigated simultaneously. Further, two different type of condenser e.g. cooling tower type and submerge coil type condenser are investigated for its performance with nano particle. Number of experiments are design by adopting DOE. Eighteen different experiments are performed with different combination of input parameters. The response of each experiment are observed in the form of cooling effect, compressor work and COP of the proposed system. The comparative results are presented to evaluate the effect of nano particle. The results indicates that 8.7% rise in cooling effect with 17.2% reduction in compressor work is observed in the proposed system as compared to convention VCR system (i.e without nano particle). Overall 22.8% rise in COP is observed in the proposed system as compared to convention VCR system for the same input parameters.

2.7 Future Work Recommendations

Based on this work, the future work recommendations are:

- The experimental investigation with other nano particles such as Cuo, Zno etc. to identify its effect and its comparison with Al_2O_3.
- Investigation of effect nano particles on water side of the proposed by system by changing the condenser.
- Performance Comparison of the system having nano particle in refrigeration side and water side.

2.8 Detailed Break-up of Expenditure with Bill

Divya Enterprise

Divya Enterprise
14, Sharnam Industries, Kathwada GIDC,
Ahmedabad, Gujarat, India
(M) +91 7600353108
E-Mail: pateldivya1904@gmail.com

TAX INVOICE

Invoice Number : 04		**Transportation :** Private Vehicle	
Invoice Date : 01/07/2023		**PAN No.:** DSPPP0073N	
Billing To		**Shipping To**	
Name :	**Mr. Om Trivedi**	Name:	**Mr. Om Trivedi**
Address :	Pandit Deendayal Energy University (PDEU), Knowledge Corridor, Raisan Village, PDPU Rd, Gandhinagar, Gujarat 382007	Address:	Pandit Deendayal Energy University (PDEU), Knowledge Corridor, Raisan Village, PDPU Rd, Gandhinagar, Gujarat 382007
State:	GUJARAT	State	GUJARAT

Sr. No.	Item Descriptions	Amount	Qty	Total Amount (RS)
01	**Nano particle assisted VCR System** • Compressor (R134a) • Fin and tube type Evaporator with centrifugal blower • Cooling tower-based copper coil condenser • Expansion valve (TXV) • HP-LP Switch, Gauges and Refrigerant R134a • MS fabricated structure with powder coating • Panel: Manual control panel with Temperature sensors, Humidity sensors and energy meter	1,00,000/-	01	1,00,000/-
Invoice Total in Words: **Rupees One Lakh ONLY.**		**Invoice Total**		**1,00,000/-**

DIVYA PRAVINBHAI PATEL
BANK NAME: STATE BANK OF INDIA
Bank Account no. : 33745264496
IFSC Code:SBIN0016060

Note: - Our risk & responsibility ceases after the delivery.

For, DIVYA ENTERPRISE

Authorized Signatory

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