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Optimal Performance Analysis of Energy Efficient Residential Air Conditioning System with Nanofluid-based Intercooler using Taguchi-based Response Surface Methodology

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Abstract: *Air conditioning is viewed as a major energy consuming area in domestic and industrial applications. However energy conservation is effectively possible in air conditioners by employing an intercooler with nanofluids, which can consequently reduce the compressor load. This paper presents an investigative report on the performance of proposed energy efficient air conditioning system. A binary mixture of ethylene glycol ($C_2H_6O_2$) and water is used as the base fluid in the shell and coil type heat exchanger (SCHE). The volume concentration of $C_2H_6O_2$ in base fluid, type of suspended nano particles (Al_2O_3 and MgO), flow rate of nanofluid at shell side of intercooler and the volume fraction of nano particles are chosen for experimentation designed using Taguchi L_{18} orthogonal array. The coefficient of performance (COP) of the nanofluid-based domestic air conditioner is estimated as the performance index (response). Quadratic model and response surface plots are generated to observe the effects of inputs on the COP. The nano particles of MgO (0.75%v/v), suspended in a binary mixture with 28.65% $C_2H_6O_2$ is found to improve the system performance (COP) at a nanofluid flow rate of 2.42 LPM.*

Keywords: Optimal performance,Nanofluid, Intercooler, Air conditioner, Coefficient of performance, Energy conservation

HIGHLIGHTS

· Informative report on optimal performance evaluation of nanofluids-based intercooling in domestic split-type air conditioner using Taguchi based response surface methodology.
· L_{18} OA was used to conduct the performance evaluation trials (reduced number of experimentations compared to CCD used with traditional RSM).
· Optimal nanofluid parameters are disclosed to offer the essential guidelines for energy conservation.
· Research findings contribute to promote the applications of these nanofluid based intercoolers for energy conservation and effective heat transfer enhancement in air conditioners (residential) and food processing industries.

1. INTRODUCTION

The reduction of greenhouse emission is a major challenge lying in front of engineers and a vital area prone to research. Improvement in the Coefficient of performance (COP) of an air conditioning system, leading to a decreased greenhouse emission has offered the necessary urge and motivation to carry out the investigation. Improved energy efficiency in systems like split type air conditioners can offer a large savings in energy consumption. This is possible with strategies prompting an increased cooling capacity, reduced compressor power and application of intelligent electronics as well. However reducing the compressor exit temperature or reducing the condenser thermal load can be an impressive method for achieving enhanced energy efficiency (Balaji et al. 2015). The conventional vapour compression cycle employed in air conditioners need more power to remove the latent heat. The technique of integrating the cooling tower with existing condenser unit by employing a cellulose pad as evaporator filler material is observed to improve the COP significantly (Hu and Huang 2005). An enhanced energy saving and performance improvement is also possible by using two cross fluted cellulose bounded structures to cool the air before entering the condenser (Hajidavalloo 2007).

Application of indirect evaporative cooling using water as a coolant, stored in a separate tank has showed a significant increase

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NOMENCLATURES

SCHE	Shell and coil type heat exchanger
COP	Coefficient of performance
RTD	Resistance temperature detector
FESEM	Field emission scanning electron microscope
EDX	Energy-dispersiveX-rayspectroscop
V	Voltage
I	Current
H	Enthalpy
W	Work done
Qc	Cooling capacity
Mref	Mass flow rate of refrigerant
ANOVA	Analysis of variance
RSM	Response surface methodology

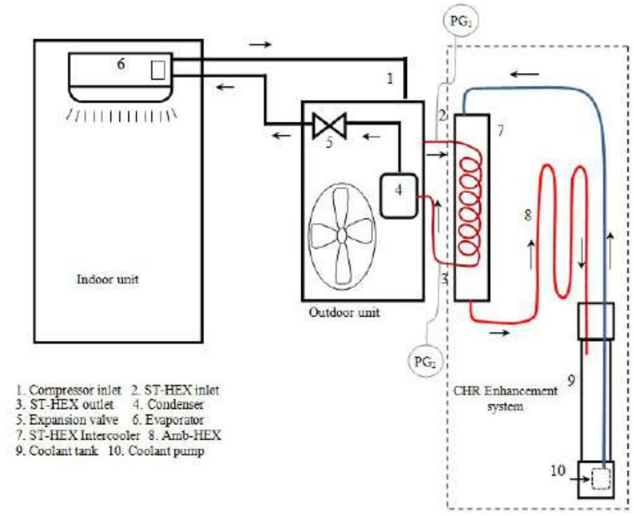

Figure 1. Schematic arrangement of the experimental setup

in COP, accompanied by a reduction in power consumption (Jessim 2011). Mathematical models predicting the heat exchange in a direct evaporative cooler can be used to predict the condition of air existing in a system (Hassan and Hanash, 2012). An evapotranspiration condenser is found to increase the heat transfer coefficient compared to an air-cooled condenser, thereby improving the performance of the air conditioning system (Thu and Sato, 2013). A structure with cellulous media pad, installed in front of air condenser is observed to bring about an improvement in energy savings (Hajidavalloo and Eghtedari, 2010). An analysis and prediction of energy saving in residential building air conditioner has proved the higher efficiency of water cooled split air conditioner compared to an air cooled one (Chen, Lee and Yik, 2008). An alternative refrigerant is proposed through irreversibility and exergy analysis for enhancing the COP (Murthy, Padmanabhan and Senthilkumar, 2013). A performance analysis in micro channel evaporator designs has shown the importance of vertical inclination angle of evaporator for an improved heat transfer in slip condition (Malvandi and Ganji, 2015).

A mixture of two refrigerants can improve the heat transfer than single conventional refrigerant alone (Ahamed, Saidur and Masjuki, 2014). A typically modelled air conditioning cooling coil incorporating an enthalpy heat exchanger can also function with improved energy efficiency (Nasif, Al-Waked and Behnia, 2013). Addition of splitter vanes in the existing systems along with the suspended nano particles in the base fluid is found to improve the heat transfer performance (Wang, Sheng and Nnanna, 2014). Suspension of nano particles in weight fractions from 0.05 % up to 0.3 % can offer better convective heat transfer characteristics. The enhancement in the convective performance is observed to be similar to one reported in well controlled systems (Gupta, Kumar and Arora, 2015). Different nanoparticles (Cu, Al_2O_3, CuO and TiO) at different volume fractions and particle diameters are observed to enhance the energy efficiency in air conditioning systems (Loaiza, Pruzaesky and Parise, 2010). A base fluid like ethylene glycol mixed with deionized water and different nano particles like silica and alumina can improve the performance of air conditioning systems (Rafati, Hamidi and Shariati Niaser, 2012). Position dependent magnetic field influences the heat transfer characteristics and heat transfer rate enhancement observed due to additional volume fraction of nano particles is true for the entire range of Rayleigh number (Soltanipour, Khalilarya and Yekani Motlagh, 2016; Akhavan-Behabadi et al. 2015).

In split-type domestic air conditioner, R-22 is used as refrigerant and a shell and coil type heat exchanger (SCHE) intercooler is employed. For enhancing the heat rejection on the condenser side, binary mixture of ethylene glycol and water based nanofluid is used as the shell side coolant. The volume concentration of $C_2H_6O_2$ in base fluid, type of suspended nano particles (Al_2O_3 and MgO), fluid flow rate at shell side of intercooler and the volume fraction of nano particles are the dominant parameters affecting the performance of SCHE intercooler and consequently the energy efficiency in air conditioning systems. Modelling the COP as a function of these parameters is essential in arriving at their optimal levels. Taguchi method of experimentation is generally followed to study effect of parameters on the responses and further analysis using grey theory and principal components can predict the optimal combination of parameters (Adalarasan and Shunmuga sundaram, 2015). Response surface methodology (RSM) is a numerical method used to form a quadratic model for further analysis within experimental domain (Adalarasan, Santhanakumar and Rajmohan, 201a5; Santhanakumar et al. 2016). The method can generate surface plots for studying the relationship between the responses and input parameters (Adalarasan, Santhanakumar and Rajmohan, 2015b).

The power consumption of compressor can be decreased by reducing the operating pressure of refrigerant. The possibility of a reduced refrigerant temperature at the outlet of condenser using fresh water/tap water for evaporative cooling is available in existing literature. However from a comprehensive review, it is ob-

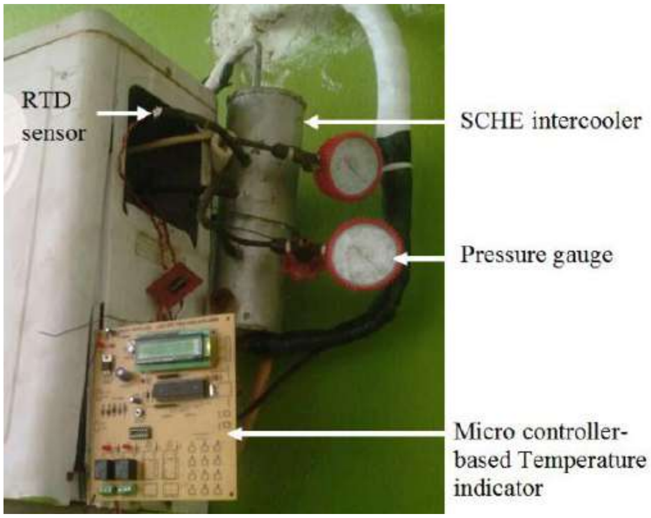

Figure 2. Photographic view of experimental setup

served that usage of a binary mixture of $C_2H_6O_2$ and H_2O as a base fluid and condenser side coolant is limited in research. Further the usage of nanofluids as coolant in intercooler and application of Taguchi based response surface methodology (RSM) for predicting the optimal parameters and hence a better COP is not available in literature. Hence the present work is focussed towards investigation in performance improvement using Al_2O_3 and MgO based nanofluids in SCHE intercooler of a split-type domestic air conditioner employing R-22 as refrigerant.

2. EXPERIMENTATION

The section discloses the experimental set-up employed for performance evaluation, types of nanofluids and dominant parameters chosen for investigation. The experimental design and procedure involving Taguchi's orthogonal array is also presented.

2.1. Experimental set-up

A split-type domestic air conditioner (LG Make: 3850A27337E) with a cooling capacity of 18,000 Btu/hr is chosen for performing the experimentations. The refrigerant employed is R-22, with a system power rating of 1850 W. The schematic arrangement of the experimental setup shown in Figure 1.and photograph of the set-up is shown in Figure 2. The expansion valve located between the condenser and inlet of evaporator operates on the opposite side of compressor in the outdoor unit. The controls of air conditioning unit are available in the in-door unit, comprising of the evaporator coil and blower fan inside the area to be cooled. The proposed set up utilizes a SCHE intercooler fitted between condenser and compressor. For condenser side heat rejection enhancement, mixture of $C_2H_6O_2$ and H_2O is used as coolant (shell side) and R-22 is used as refrigerant (tube side). The novelty of the work lies in employing the nanofluids for heat transfer in intercooler. The refrigerant is passed through a helical copper tube (external diameter- 9.5 mm and internal diameter- 7.8 mm) and austenitic stainless steel (Grade 304L) is employed as the shell material. The intercooler decreases the pressure ratio between the evaporator and condenser, assisting in a reduced refrigerant pressure head requirement of compressor (Balaji et al. 2015).

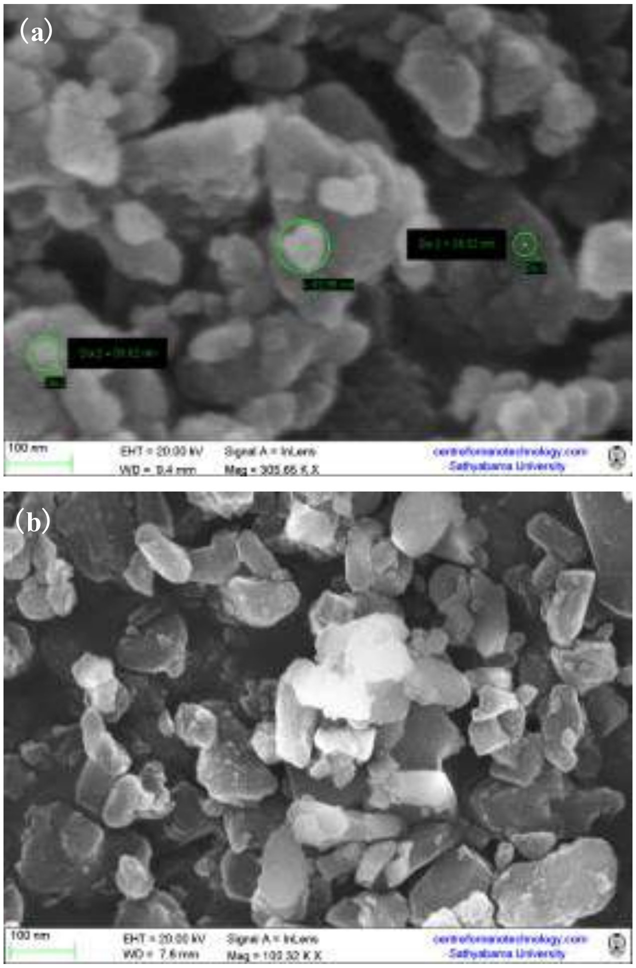

Figure 3. FESEM image of nano particles suspended in base fluid (a) alumina (b) MgO

The refrigerant experiences a change in phase and enters the expansion valve and finally to the evaporator to complete the cycle. The air through the condenser is first allowed via a finned tube heat exchanger to remove the heat of the nanofluid. For achieving a convective thermal loss, the aluminium tubes are subjected to frequent cleaning. The flow rate of coolant is controlled by a pump (capacity- 12 W), which ensures proper circulation via a coolant tank (capacity- 5 L) made of PVC. Bourdon gauges (accuracy- ±0.05 bar) and power meter with digital display are used for pressure and power consumption measurements, while RTD sensors are used for measuring the temperature at desired locations. The heat from the refrigerant is absorbed in a convection heat transfer mode in the helical coils of SCHE intercooler.

2.2 Nanofluids

The base fluid is mixed with nano particles of alumina and magnesium oxide to form nanofluids of desired concentration. Relatively spherical shaped nanoparticles are suspended in the base fluid (binary mixture of $C_2H_6O_2$ and H_2O in different proportions). Both

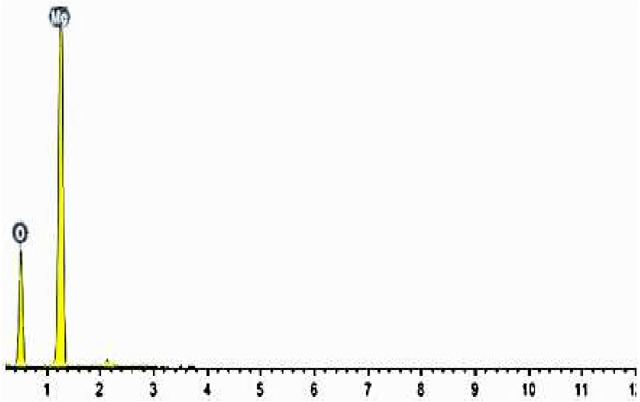

Figure 4. EDX test on MgO nano particles

Figure 5. Magnetic stirring of MgO based nanofluid mixture

the alumina and magnesium oxide nanofluids are prepared with different concentrations taking into account the individual impacts of both base fluid and nano particles on the performance improvements ((Balaji et al. 2015; Ruan and Jacobi et al. 2012).The FESEM images show the nano particles used in preparing the nanofluids (Figure 3). The size of nanoparticles used is in the range of 50 nm to 85 nm. The Al_2O_3 and MgO nanoparticles are tested for purity and uniformity in crystal size before the preparation of nanofluids(Scherrer 1918).

The elemental analysis (EDX) is performed to ensure higher purity levels of both the nano particles. The report of EDX test on MgOnano particles is disclosed in Figure 4.Sodium dodecyl benzenesulfonate (SDB) is added as a dispersant to improve the stability of nanofluids (Balaji et al. 2015). The continuous circulation of nanofluids, along with the presence of SDB ensures a prolonged settling time. Regular usage of system in residential sector will aid the prevention of settling as well.The preparation includes the following stages: adding the dispersant to base fluid and subjecting it to ultrasonification for 120 min, followed by the addition of nano particles and further ultra-sonification for 240 min.

The resulting nanofluid mixture is magnetically stirred (Figure 5) to ensure stability for duration of ten days (Balaji et al. 2015; Raveshi et al. 2013). The values of effective viscosity (Mishra et al. 2014;Esfe, Saedodin, and Mahmoodi, 2014) and effective thermal conductivity (Peyghambarzadeh et al. 2011; Esfe, Saedodin, and Mahmoodi, 2014) for different concentrations of the nanofluid are estimated using various proven models (Equations (1-3)) and are shown in Table 1.

This approach has to be observed to effective and the experimental values coincide with the classical models. Since the experimentation is conducted in a relatively shorter time, the properties remain unchanged; however an intensive study is required to observe the variations after a prolonged service time.

Table 1. Effective thermo-physical properties of nano particles and nanofluids

Sl.No	Nano particles	Thermalconductivity K (W/mK)
1	Al_2O_3	36
2	MgO	48

Nano particle	Nanofluid ratio ($C_2H_6O_2$:H_2O)	Volume fraction of nano particles (%)	K (W/mK)	μ_{nf} (Kg/m.s)
Al_2O_3	20:80	0.25	0.4089	0.00249
	20:80	0.5	0.4119	0.00254
	20:80	0.75	0.4148	0.00260
	30:70	0.25	0.3783	0.00385
	30:70	0.5	0.3810	0.00393
	30:70	0.75	0.3838	0.00401
	40:60	0.25	0.3473	0.00520
	40:60	0.5	0.3498	0.00531
	40:60	0.75	0.3523	0.0054

Nano particle	Nanofluid ratio ($C_2H_6O_2$:H_2O)	Volume fraction of nano particles (%)	K (W/mK)	μ_{nf} (Kg/m.s)
MgO	20:80	0.25	0.4089	0.00246
	20:80	0.5	0.4119	0.0025
	20:80	0.75	0.4149	0.0025
	30:70	0.25	0.3783	0.00380
	30:70	0.5	0.3811	0.0038
	30:70	0.75	0.3839	0.00385
	40:60	0.25	0.3473	0.00514
	40:60	0.5	0.3498	0.00517
	40:60	0.75	0.3524	0.0052

$$\mu_{nf,Batchelor} = (1 + 2.5\emptyset + 6.5\emptyset^2)\mu_f \quad (1)$$

$$\mu_{nf,wang} = (1 + 7.3\emptyset + 123\,\emptyset^2)\mu_f \quad (2)$$

$$k_{nf} = \frac{k_p + (\emptyset - 1)k_{bf} - \emptyset(\emptyset - 1)(k_{bf} - k_p)}{k_p + (\emptyset - 1)k_{bf} + \emptyset(k_{bf} - k_p)}\,k_{bf} \quad (3)$$

Where $\mu_{nf}$is thenanofluid effective viscosity, μ_f is base fluid viscosity, ö is the volume concentration, K_{nf} is the effective thermal conductivity of nanofluid, $K_p$is the thermal conductivity of nano particle and K_{bf} is base fluid thermal conductivity.

2.3. Experimental design and procedure

A binary mixture of $C_2H_6O_2$ and H_2O is used as the base fluid in SCHE intercooler. The inter cooler using a coolant which is mixture of water and anti-freezing materials like ethylene glycol with different ratio is observed to produced considerably lesser cooling time (Balaji and Suresh mohan kumar, 2013). The volume concentration of $C_2H_6O_2$ inbase fluid, type of suspended nano particles (Al_2O_3 and MgO), fluid flow rate at shell side of intercooler and the volume fraction of nano particles are chosen as the dominant parameters for experimentation. Taguchi's L_{18} orthogonal array (mixed) is employed to conduct the trial runs. The parameters and their levels are chosen based on the existing literature (Balaji et al. 2015; Ratafi, Hamidi and Shariati Niaser, 2012; Soltanipour, Khalilarya and Yekani Motlagh, 2016; Akhavan-Behabadi et al. 2015;Ruan and Jacobi, 2012). The COP is estimated as the response for various combinations of input parameters and the trials are conducted at random to dodge the effects of extraneous factors (Adalarasan, Santhanakumar and Rajmohan, 2015a; Santhanakumar et al. 2016). The estimated COP values are listed in Table 2 along with the compressor work and refrigeration effect.

The air conditioner is switched on initially to obtain the desired cooling effect and the measurements are recorded at an indoor unit temperature (initial set point) of 28°C. Finally measurements are also noted after reaching a temperature (final set point) of 18°C. The operation time of the compressor to attain the required cooling effect is recorded between the initial and final set point temperature. System efficiency improvement can be realized by the reduction in the compressor operating time due to a decreased compressor load (Balaji et al. 2015).

The performance of the system is expressed in terms of COP calculated from the temperature and pressure measurements. The equations (4-7) are used to find the estimated system response (COP).

$$Totalworkdonepersec(W_T) = W_{Comp} + W_{fan} + W_{Pump} = V(I_c + I_f + I_p)cos\varphi \quad (4)$$

$$Massflowrateofrefrigerant(m_{ref}) = W_{comp}/(H_2 - H_1) \quad (5)$$

Table 2. Parameter combinations and obtained response (COP) values

Trial	Type of nano particles	Volume concentration of $C_2H_6O_2$ inbase fluid (%v/v)	Volume fraction of nano particles (%v/v)	Flow rate of Nano fluid (LPM)	Compressor work (CW) KJ/Kg		Refrigeration effect (Re) KJ/Kg		COP	
					R1	R2	R1	R2	R1	R2
1	Al_2O_3	20	0.25	1.5	33.45	33.56	169.90	170.01	4.682	4.678
2		20	0.5	2.5	29.64	29.78	170.25	170.3	5.858	5.861
3		20	0.75	3.5	27.44	27.56	171.62	171.9	5.470	5.480
4		30	0.25	1.5	33.00	33.12	170.38	169.90	4.886	4.847
5		30	0.5	2.5	29.00	29.38	170.69	170.20	5.747	5.752
6		30	0.75	3.5	27.05	27.30	172.60	172.01	5.454	5.434
7		40	0.25	2.5	29.81	29.60	170.10	169.8	5.574	5.567
8		40	0.5	3.5	28.60	28.51	172.00	171.9	5.435	5.446
9		40	0.75	1.5	30.30	30.40	171.40	171.3	5.230	5.242
10	MgO	20	0.25	3.5	28.60	28.86	171.60	171.4	5.554	5.546
11		20	0.5	1.5	30.01	29.80	170.50	169.8	5.466	5.463
12		20	0.75	2.5	27.50	27.76	172.50	171.90	5.975	5.963
13		30	0.25	2.5	29.80	30.01	172.20	171.92	5.842	5.779
14		30	0.5	3.5	25.45	25.20	172.60	172.23	6.154	6.122
15		30	0.75	1.5	29.01	29.35	172.50	172.35	6.573	6.598
16		40	0.25	3.5	28.40	28.60	171.80	171.6	5.910	5.914
17		40	0.5	1.5	29.40	29.20	172.00	171.8	5.870	5.863
18		40	0.75	2.5	27.40	27.20	172.80	172.5	6.041	6.034

$$Cooling capacity \; = Q_c = m_{ref}(H_1 - H_4) \tag{6}$$

$$COP \; = Q_C/w_T \tag{7}$$

Where W_{comp} is the compressor work, W_{fan} is the fan work and W_{pump} is the pump work in KW. H_2-H_1 is the enthalpy change in the compressor (KJ/Kg.K) and H_1-H_4 is the change in enthalpy in the evaporator (KJ/Kg.K).

3. PROCEDURE FOR SELECTING THE OPTIMAL NANOFLUID PARAMETERS USING RSM

Response surface methodology is a statistical method of generating a model, linking the input parameters with the responses. The method involves the generation of a mathematical model and response surface plots for better understanding of the system. RSM involving the following steps is generally supplemented by the desirability analysis for predicting the optimal level (Adalarasan, Santhanakumar and Rajmohan, 2015a; Santhanakumar et al. 2016).

Step 1: Construct a mathematical model (polynomial equation of second order /cubic equation) for COP, offering a substantial scope to understand the system behaviour.

Step 2: Conduct the variance analysis (ANOVA) to study the significance of nanofluid parameters and their contribution in affecting the system performance.

Step 3: Plot the interaction graphs to observe the individual and interaction effects of the parameters chosen for study.

Step 4: Predict the optimal parameter levels using desirability analysis.

Step 5: Perform the confirmation tests for validating the proposed approach.

4. RESULTS AND DISCUSSION

4.1 Cubic model for COP

The experimental trials are conducted using Taguchi's L_{18} array. A central composite design (CCD) and Box Behnken (BBD) is generally used with RSM technique, however a L_{18} array is used to decrease the number of experimental trials. During the initial stage of analysis, a mathematical model is formed relating the volume fraction of nano particles and fluid flow rate with the COP. A quadratic model is deemed unfit because of a negative R-squared value (predicted), indicating the exclusion of significant terms. Hence cubic models are developed with significant model coefficients using Design Expert software (version: 7.0.0). The model presented in Eq. (8) and Eq. (9) for the COP can predict the trial results.

$$COP\,(Al_2O_3) = -3.76156 + 0.29362 * B + 10.29340 * C + 3.40480 * D - 0.23127 * B * C - 0.037508 * B * D - 6.21520 * C * D - 3.78083\times10^{-3} * B^2 + 5.65360 * C^2 + 0.043050 * D^2 + 0.075080 * B * C * D \tag{8}$$

$$COP\,(MgO) = -3.04522 + 0.37417 * B + 10.09522 * C + 1.37431 * D - 0.25453 * B * C - 0.037508 * B * D - 3.08650 * C * D - 3.78083\times10^{-3} * B^2 + 0.76800 * C^2 + 0.043050 * D^2 + 0.075080 * B * C * D \tag{9}$$

Table 3. ANOVA result

Source	Sum of squares	Degrees of freedom	Mean sum of square	F value	p-value
Model	6.91	17	0.41	1736.3	< 0.0001
A-Type of nano particles	0.079	1	0.079	337.5	< 0.0001
B-Volume concentration of $C_2H_6O_2$ in base fluid	0.099	1	0.099	421.07	< 0.0001
C-Volume fraction of nano particles	3.89E-03	1	3.89E-03	16.61	0.0007
D- Flow rate of nanofluid	0.26	1	0.26	1111.56	< 0.0001
AB	0.22	1	0.22	936.75	< 0.0001
AC	0.27	1	0.27	1159.89	< 0.0001
AD	0.18	1	0.18	768.37	< 0.0001
BC	0.057	1	0.057	244.09	< 0.0001
BD	3.01E-07	1	3.01E-07	1.29E-03	0.9718
CD	0.89	1	0.89	3781.56	< 0.0001
B^2	0.57	1	0.57	2443.2	< 0.0001
C^2	0.026	1	0.026	112.37	< 0.0001
D^2	9.27E-04	1	9.27E-04	3.96	0.062
ABC	3.38E-03	1	3.38E-03	14.45	0.0013
ACD	0.06	1	0.06	258.19	< 0.0001
BCD	0.023	1	0.023	100.36	< 0.0001
AC^2	0.036	1	0.036	151.77	< 0.0001
Pure Error	4.21E-03	18	2.34E-04		
Cor Total	6.91	35			

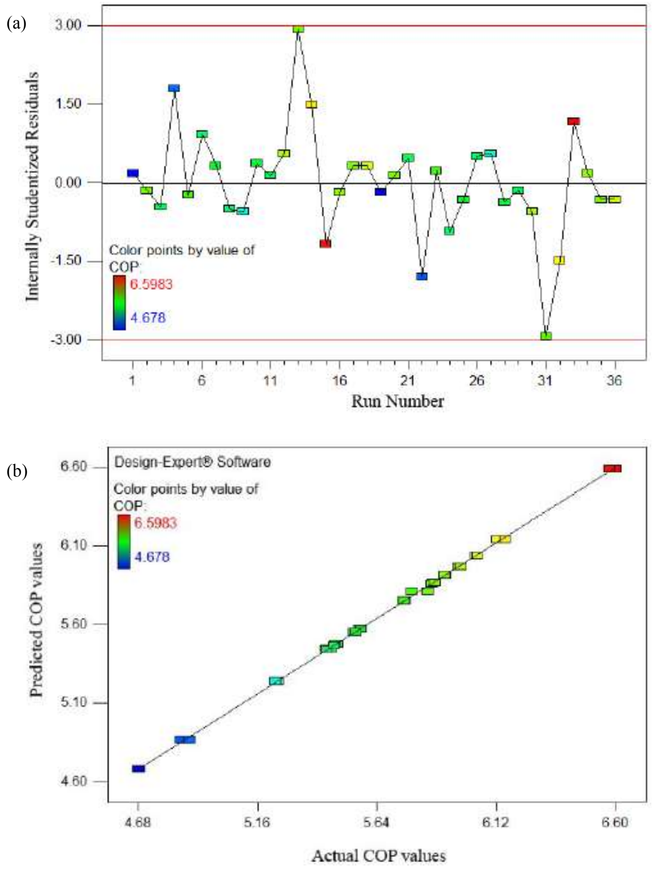

Figure 6. (a) Residual plot (b) plot of predicted versus actual COP values

4.2. Analysis of variance

Analysis of variance is performed to find the worth of model coefficients and fitness of generated model in expressing the link among the inputs and COP. The ANOVA results are shown in Table 3. The F-value (1736.43) gives the evidence for model significance and the significance of model terms is shown by the "p-value" (less than 0.05). The higher F-value for the cubic model due to uncontrollable factors is lesser (0.01%). The first order of input parameters A, B, C and D, interaction terms AB, AC, AD, BC and CD, second order of terms B and C and cubic interactions ABC, ACD and BCD are observed to be significant from the results of ANOVA. The closeness of R-squared value (0.99) to one (Table 4), presents a good degree of fitness between the generated cubic model and the obtained experimental data. The adjusted R-squared value is in good agreement with the predicted R-squared value showing a lesser degree of scatter. A higher value of adequate precision (176.165) displays enough proof for model discrimination. The ANOVA table has revealed the fitness and adequacy of the cubic model generated for COP. The residual plot (Figure 6(a)) displays the absence of any trends and most of the values are observed to fall close to the centre line indicating the goodness of fit (Figure 6 (b)).

Table 4. R-squared value and adequate precision

Std. Dev.	0.015	R-Squared	0.9994
Mean	5.65	Adj R-Squared	0.9988
C.V. %	0.27	Pred R-Squared	0.9976
PRESS	0.017	Adeq Precision	176.165

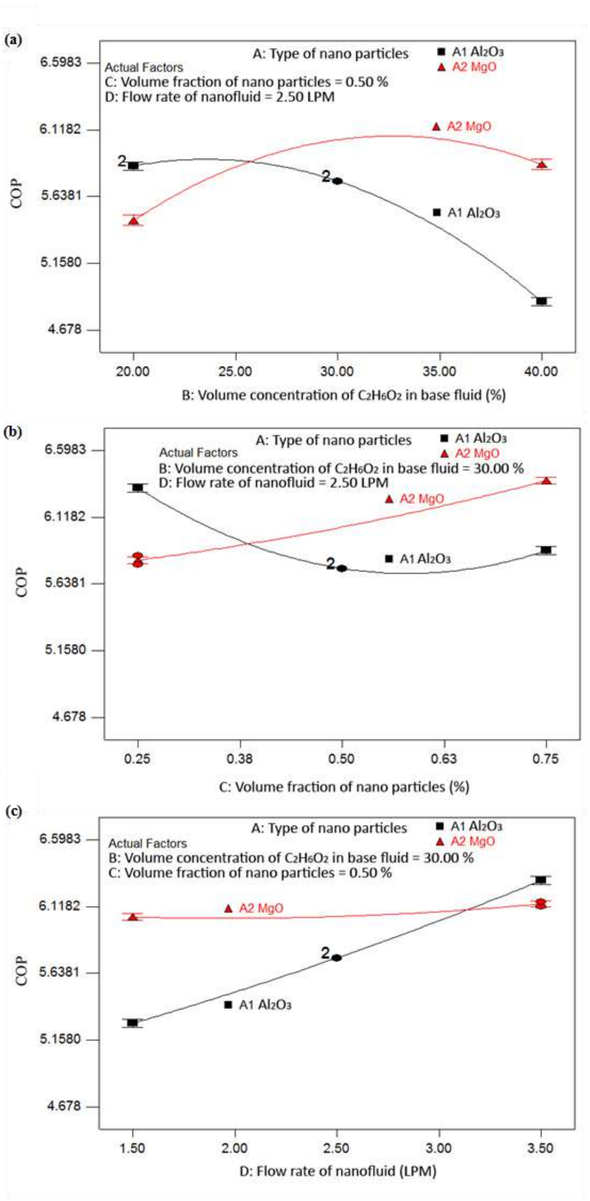

Figure 7. Interaction plots.

4.3. Interaction plots and response surface graphs related to process mechanics

The interaction plots are generated and shown in Figure 7. An increase in the concentration of the base fluid is observed to improve the COP, however beyond a certain level of ethylene glycol in base fluid, the COP is found to decrease (Figure 7(a)). This can be attributed to the increase in viscosity of the base fluid

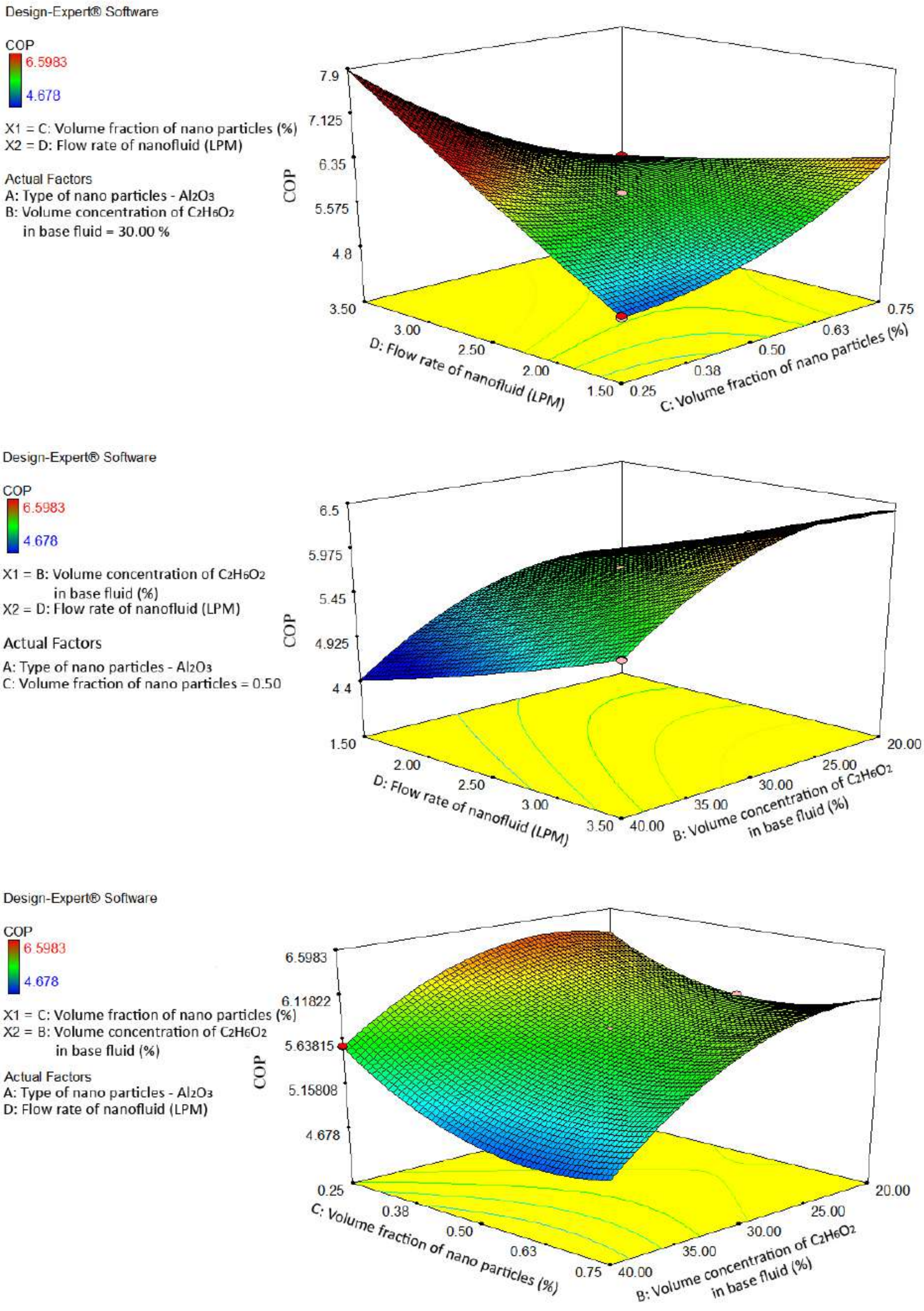

Figure 8. Response surface plots

(reduced water content), accompanied by a reduction in heat absorption characteristics. A sharp reduction in COP is observed with alumina based nanofluid compared to MgO based nanofluid (Figure. 7(b)), due to the better conducting characteristics of MgO compared to alumina nano particles. A lower volume fraction of alumina nano particles in base fluid results in a higher COP, however an increase in the volume fraction of MgO in base fluid improves COP significantly (Figure 7b & 7c). MgO is a poor desiccant and with an improved wettability can enhance the heat transfer characteristics as well.An improvement in flow rates of alumina based nanofluid enhances the COP significantly compared to the MgO based nanofluid. The observations are deemed fit within the range of experimentation.

The three dimensional plots (Figure 8) are also generated to observe the interaction effects of design variables (Flow rate of nanofluid, volume fraction of nano particles and volume concentration of $C_2H_6O_2$)on the COP. The response surfaces generated show similar effects observed via the interaction plots. An increased flow rate of nanofluid and volume fraction of nano particles is observed to enhance the heat transfer characteristics.

4.4. Desirability analysis for optimal level selection and validation trials

The Design Expert software is used to perform the desirability analysis using the larger-the-better desirability function. The input conditions producing the highest value of desirability is chosen as the best condition within the experimental domain. The optimal level of parameters for better COP is identified as: volume concentration of $C_2H_6O_2$ in base fluid- 28.65 %v/v, volume fraction of nano particles- 0.75 and flow rate of nanofluid- 2.75 LPM (Table 5). A proper validation of optimal parameter setting becomes essential to authorize the technique followed in analysis. The COP obtained with the two different nanofluids is compared. It is found that a higher value of COP is obtained with MgO based nanofluid. This coincides with the research findings in literature (Xie, Yu and Chen, 2010). The confirmatory test proves the improvement obtained in COP, authorizing the methodology adopted for analysis.

5. CONCLUSIONS AND FUTURE SCOPE

The paper investigates the usage of nanofluids (nano particles suspended in a binary mixture of $C_2H_6O_2$ and H_2O as base fluid) as coolant in SCHE intercooler of a split type domestic air conditioner, employing R-22 as refrigerant. Taguchi based response surface methodology (RSM) is used to predict the optimal nanofluid parameters for obtaining an improved COP. The following conclusions can be drawn.

- The compressor work is decreased by using the nanofluid as coolant in SCHE intercooler. The nanofluid is used to cool the refrigerant (R-22).
- An increase in volume fraction of MgO nano particles in the base fluid improves the COP significantly compared to an increase in volume fraction of alumina nano particles.
- A higher level of ethylene glycol in base fluid, with nano particles suspended in it is found to decrease the COP of split type domestic air conditioner. However an improved flow rate of nanofluid improves the system performance.
- The optimal level of parameters for an improved COP is identified as: volume concentration of $C_2H_6O_2$ of base fluid- 28.65 %v/v, volume fraction of nano particles- 0.75 %v/v and flow rate of nanofluid- 2.75 LPM. However MgO based nanofluid is found to outperform the alumina based nanofluid for a similar optimal condition.

The research findings will assist in improving the energy savings in a split type domestic air conditioner employing R-22 as refrigerant. Further it will be a precursor to reduce global warming by way of reducing the green-house emission. The future scope lies in analysing the possibility of employing a similar approach in household refrigeration systems as well.

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Table 5. Desirability analysis and validation trial result

Factor	Name	Level	Low Level	High Level
A	Type of nano particles	Al_2O_3/MgO	Al_2O_3	MgO
B	Volume concentration $C_2H_6O_2$ of base fluid	28.65	20	40
C	Volume fraction of nano particles	0.75	0.25	0.75
D	Flow rate of nano fluid	2.42	1.5	3.5
Response	**Prediction**	**SE Mean**	**95% CI low**	**95% CI high**
COP (Al_2O_3)	6.09334	0.02	5.95	6.04
COP (MgO)	6.80563	0.097	6.6	7.01
Response	**Confirmation Trial**	**Trial 1**	**Trial 2**	**Average COP**
COP (Al_2O_3)	B=28.65 %v/v, C=0.75 %v/v, D=2.41 LPM	5.974	5.993	5.9835
COP (MgO)	B=28.65 %v/v, C=0.75 %v/v, D=2.41 LPM	6.925	6.886	6.9055

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