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Research Paper

Performance Optimization of Automotive Air-Conditioning System Operating with Al_2O_3-SiO_2/PAG Composite Nanolubricants using Taguchi Method

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Abstract

The performance of an automotive air-conditioning (AAC) system is influenced by a variety of operating conditions. This can be addressed by employing optimization techniques that can suggest the appropriate parameters for the best results. In this study, the optimum operating conditions for a composite nanolubricants-fuelled AAC system were investigate using Taguchi's design of experiment approach and analysis of variance (ANOVA). The motor speed value, initial refrigerant charge, and composite nanolubricants composition ratio were chosen as operating parameters to investigate the AAC system performance, focusing on the coefficient of performance (COP) and compressor work. Orthogonal arrays (ORs) L_{25} (5^6) was selected to determine the optimum operating parameters of the AAC system. The optimum values for speed, refrigerant mass, and composition ratio were determined to be $A^4B^1C^5$ (60:40, 900 rpm and 155 g), respectively. The motor speed was the significant factor influencing both COP and compressor performance by 78.13% and 89.29%. A confirmation test was conducted with the optimum levels of AAC system parameters to verify the efficiency of the Taguchi optimization method. The validation between the optimization results and the experimental results yielded a maximum error of 9.85%, indicating that the findings of this investigation were acceptable.

Keywords: ANOVA; Automotive air-conditioning; Hybrid nanolubricants; Taguchi methods; Optimization

1. Introduction

Optimization techniques are developed to evaluate the optimum parameters of system parameters to provide the best performance. Finding crucial parameters in data analysis that determine causality would greatly improve the total research output [1], [2]. Recently, researchers have been giving considerable attention to optimize system performance via software networks like Minitab and Design Expert [3]-[5]. In the recent decade, this is possible with the introduction of advanced computer hardware [6], innovative digital computer technology [7] and advanced simulation software. For this reason, rapid growth in research development of statistical models progressed to analyse and optimize the operating parameters. The investigation of AAC systems by experimental work has consumed much time and cost; therefore, the optimization approaches are reliable to optimize the system parameters towards the desired performance. The most popu-

Nomenclature	
COP	Coefficient of Performance
AAC	Automotive Air Conditioning system
rpm	Revolution per minute
PAG	Polyalkylene glycol
m	Mass, g
T	Temperature, °C
RSM	Response Surface Method
OR	Orthogonal arrays
FESEM	Field emission scanning electron microscopy
EDX	Energy Dispersive X-Ray Analysis
S/N ratio	Signal-to-noise ratio
ORC	Organic Rankine Cycle
A	Composition ratio of composite nanolubricants
B	Compressor speed
C	Initial Refrigerant Charge
Eq.	Equation
Greek Symbols	
ϕ	Volume concentration, %
ρ	Density, kg/m^3
μ	The square of mean
σ	Variance
Subscripts	
cnl	Composite nanolubricant
L	Lubricant
p	Nanoparticle

lar methods for optimization are the Taguchi method [8]-[11] and Response Surface Method (RSM) [12]-[15].

The Taguchi method has been successfully applied for various systems, materials, with very high complexity, in several scientific, engineering, and industrial fields [16]-[18]. In addition, this method uses analytical, statistical, and mathematical methodologies to determine the most effective parameters for overall performance. With few experiments, this approach has a low-cost development cycle [19]-[21]. It is knowns for its ability to optimize multiple variable effects alongside with interaction effects [22]. The method is used to play a key role in experimental design with multiple parameter problems and acted as an alternative approach [23]. Krishankant et al. [24] stressed that studying the response variation using the S/N ratios is important in the data analysis. The objective function results are converted into the signal-to-noise (S/N) ratios. The S/N ratios analysis allows for the control of many parameters in order to limit parameter changes and adjust the experimental process while maintaining the same experimental conditions, resulting in improved response analysis and physical properties [18]. S/N ratios analysis is utilized by the Taguchi method to measure the deviation of the desired value for the quality of the characteristic [25]. The characteristic of the S/N ratios can be divided into three types: the-lower-the-better, the-larger-the-better, and nominal-is-better. S/N ratios can be determined by observing the effects of each parameter on the objective function. Furthermore, the level with maximum S/N ratios represents the optimum level of design parameters. Thus, optimum parameters for better performance can be acquired by obtaining the greatest S/N value [24].

Some studies considered the utilization of the Taguchi method to find the optimum operating conditions in different mechanical applications. Yakut et al. [26] investigated the influence of different design parameters on the heat transfer and pressure drop characteristics of the heat exchanger using the Taguchi method. Later, Turgut et al. [27] examined the concentric heat exchanger with injector turbulators at different angles, diameters and numbers. They studied the effects of the parameters on heat transfer and pressure loss. The Taguchi method was used to evaluate the optimum design parameter for the turbulators. Coşkun et al. [28] suggested a Taguchi approach for optimizing the performance by determining the significant parameters and optimum operating conditions of waste heat recovery. Arslanoglu, Yigit [29] studied the most significant parameter effects on the optimum insulation thickness using the Taguchi method while ANOVA analysis calculated the impact ratios for each parameter. In the recent work, Bademlioglu et al. [30] exploited both the Taguchi method and ANOVA analysis to investigate the impact weights of parameters on the Organic Rankine Cycle (ORC) first-law of efficiency. They reported 70% of the measured total effect ratios of these parameters. An efficient and systematic way of design optimization for performance, quality and cost is provided by the Taguchi method. This is due to its approaches in determining the best output performance of various parameters [30]. However, as per author's knowledge, the Taguchi method is still not reported in literature for the optimization of the AAC system conditions.

To date, few studies are available in the literature which employ the optimization approaches in order to optimize refrigeration system efficiency [3], [31] and AAC system performance [4] which is limited to single-component nanolubricants. **Table 1** provides the list of previous studies for optimization using Taguchi method in various applications. No research has been published using compound optimization techniques for the AAC system parameter with the use of composite nanolubricants. Therefore, the current study will concentrate on the optimization investigation of composite nanolubricants on the performance of an AAC system. The Taguchi method is used to investigate the effect of AAC system parameters such as composite nanolubricants composition ratios, compressor speeds, and initial refrigerant charges on AAC system performance, specifically COP and compressor work (W_{in}). The orthogonal arrays of Taguchi, the S/N ratios, the ANOVA, and regression analyses are employed to determine the optimum composition ratios for AAC systems utilizing composite nanolubricants. Finally, a confirmation test with the optimal levels of AAC system parameters was performed to demonstrate the effectiveness of Taguchi's optimization method.

Table 1. Previous Studies on Approach of Taguchi Methods

Authors	Year	Approaches	Study
Kıvak [53]	2013	Taguchi method and regression analysis	The machinability of Hadfield steel with PVD TiAlN- and CVD TiCN/Al_2O_3-coated carbide inserts under dry milling conditions.
Balki et al. [57]	2016	Taguchi's design of experiment method and analysis of variance (ANOVA)	Engine tests in a spark ignition (SI) engine fuelled with pure gasoline, ethanol and methanol.
Bademlioglu et al. [30]	2018	Taguchi and ANOVA	Organic Rankine Cycle's (ORC) performance
Ansari et al. [22]	2018	Taguchi and ANOVA	Performance and emission analysis of a diesel engine implementing polanga biodiesel
Esen, Turgut [58]	2015	Taguchi method	Vertical ground coupled heat pump (VGCHP) system
Ji et al. [59]	2018	Taguchi and ANOVA	Thermoelectric generation for waste heat recovery
Derdour et al. [55]	2018	Taguchi analysis and response surface methodology (RSM)	Penetration rate in rotary percussive drilling
Adewale et al. [60]	2017	Taguchi	Enzyme-catalysed biodiesel production from crude tall oil
Rama, Padmanabhan [61]	2012	Taguchi methods and ANOVA	Electrochemical machining of Al/5% SiC composites
Rao, Venkatasubbaiah [62]	2016	Taguchi methods and ANOVA	Surface roughness in CNC turning
Chandrashekar et al. [63]	2017	Taguchi approach	Experimental Investigation of Turning of EN-9
Jeykrishnan et al. [64]	2016	Taguchi methods and ANOVA	EN24 Tool steel in Electro-Discharge Machining (EDM)
Krishankant et al. [24]	2012	Taguchi Method	EN24 steel in Turning process
Rathi, Jakhade [25]	2014	Taguchi method, ANOVA and regression analysis	Forging process defects in an industry case
Kumar, Sameera Simha [65]	2012	Taguchi methods and ANOVA	Experimental Investigation on Seismic Resistance of Recycled Concrete in Filled Steel Columns
Canel et al. [66]	2019	Taguchi	Laser treating of Al 6082-T6
Canbolat et al. [31]	2019	Taguchi and ANOVA	Absorption refrigeration systems
Shayestefar et al. [5]	2021	Taguchi and ANOVA	Optimization of the structural and magnetic properties of $MnFe_2O4$ doped by Zn and Dy using Taguchi method

2. Method

2.1. Preparation of Al_2O_3-SiO_2/PAG Composite Nanolubricants

The two-step method [32]-[36], [67] is used in the current study to prepare the Al_2O_3 and SiO_2 nanolubricants with PAG 46 as the base lubricant. **Table 2** provides the properties of the nanoparticles and the PAG 46 lubricant at atmospheric pressure [37]-[42]. The ISO 46 viscosity class DENSO ND-oil 8 is recommended for use with R134a refrigerant [43]. Furthermore, PAG 46 oil is more compatible with the materials used in pipe connections, such as aluminium pipe and rubber. PAG lubricants were designed exclusively for the use of compressor air-conditioning in automobiles and large vehicles. For the prevention and reduction of nanohazard exposure, hazard management during nanoparticle handling must be strictly controlled. **Eq. 1** is used to calculate the volume concentration of nanolubricants.

$$\phi = \frac{m_p/\rho_p}{m_p/\rho_p + m_L/\rho_L} \times 100 \qquad (1)$$

Where, φ is the volume concentration of nanolubricants (%), m_p is the nanoparticle mass (g), ρ_p is the nanoparticle density (kgm^{-3}), m_L is the lubricant mass (g) and ρ_L is the lubricant density (kgm^{-3}). Field emission scanning electron microscopy (FESEM) and Energy Dispersive X-Ray Analysis (EDX) analysis are used to confirm the sizes and the elemental composition of the nanoparticles before preparation of composite nanolubricants. Other researchers [37], [44]-[49], [68], [69] also adapted similar methods in their studies. **Figure 1** displays the FESEM image of Al_2O_3 and SiO_2 nanoparticles with average diameter of 13 nm and 30 nm, respectively. Both nanoparticles were found to be spherically shaped. **Figure 2** shows EDX images of specimens with elemental content for various nanoparticles used in the study.

The Al_2O_3-SiO_2/PAG nanolubricants was prepared using the two-step preparation method for volume concentration of 0.06% at different composition ratios. The Al_2O_3/PAG and SiO_2/PAG nanolubricants were made separately at first. Next, both nanolubricants were added to form Al_2O_3-SiO_2/PAG nanolubricants with a 60:40 composition ratios. The nanolubricants were then mixed for 30 minutes using a magnetic stirrer before being sonicated for up to 2 hours. **Figure 3** depicts the composite nanolubricant preparation

Table 2. Properties of Nanoparticles and PAG 46 Lubricants at Atmospheric Pressure [37]-[42]

Properties	Units	Al_2O_3	SiO_2	PAG 46
Molecular mass	g mol^{-1}	101.96	60.08	-
Average particle diameter	nm	13	30	-
Density	kg m^{-3}	4000	2220	-
Thermal conductivity	W m^{-1}K^{-1}	36	1.4	-
Specific heat	J kg^{-1}K-1	773	745	-
Density @ 293 K	g/cm^3	-	-	0.9954
Flash Point	K	-	-	447
Kinematic viscosity @ 313 K	cSt	-	-	41.4 - 50.6
Pour Point	K	-	-	222

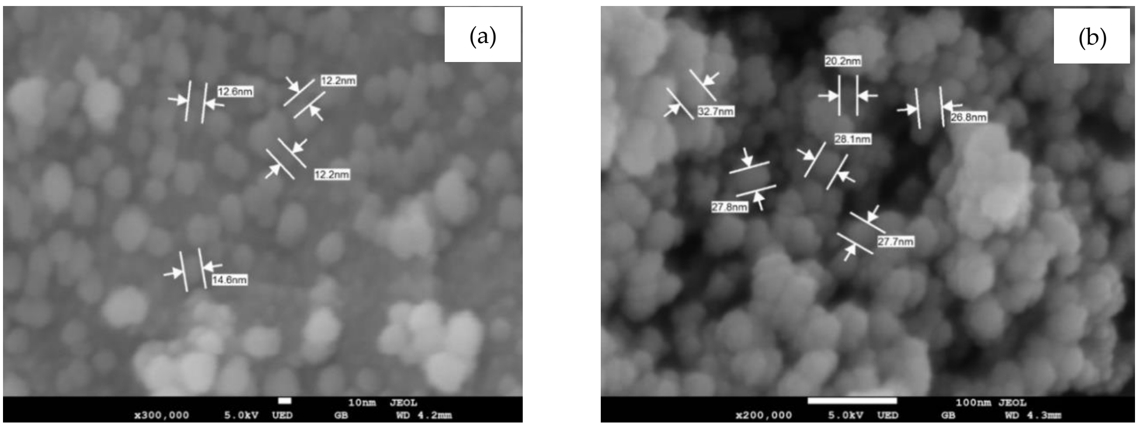

Figure 1. FESEM Images of The Metal Oxide Nanoparticles (a) Al_2O_3 nanoparticles (b) SiO_2 nanoparticles

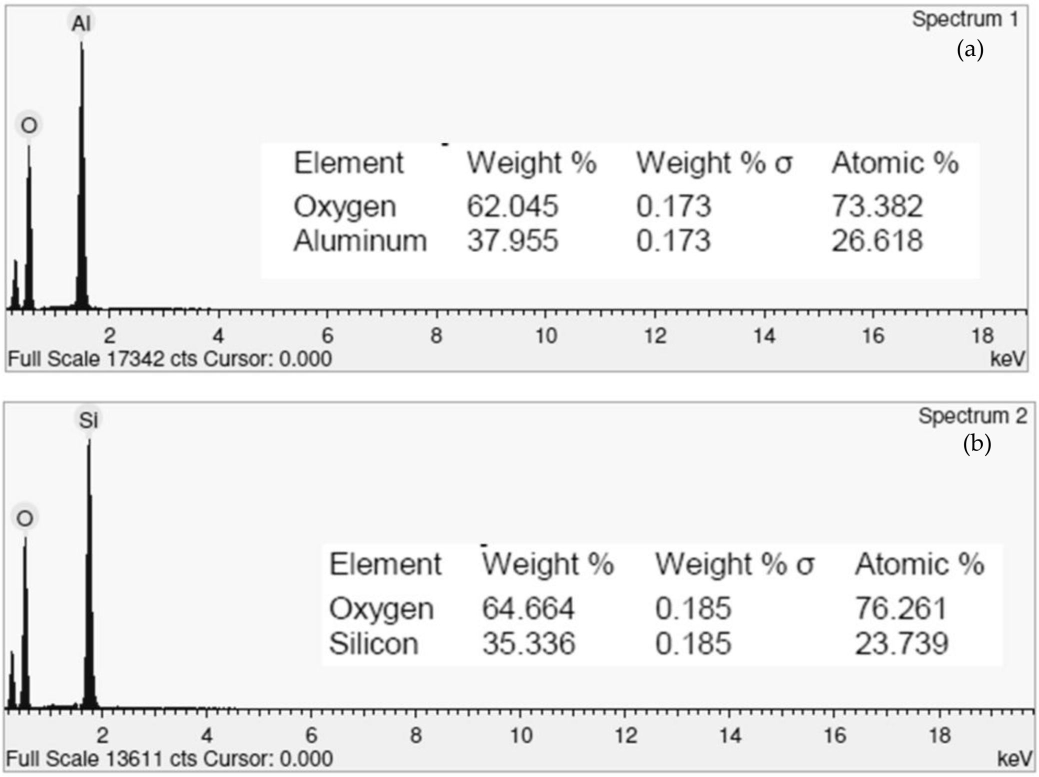

Figure 2. EDX Analysis of The Metal Oxide Nanoparticles (a) Al_2O_3 nanoparticles (b) SiO_2 nanoparticles

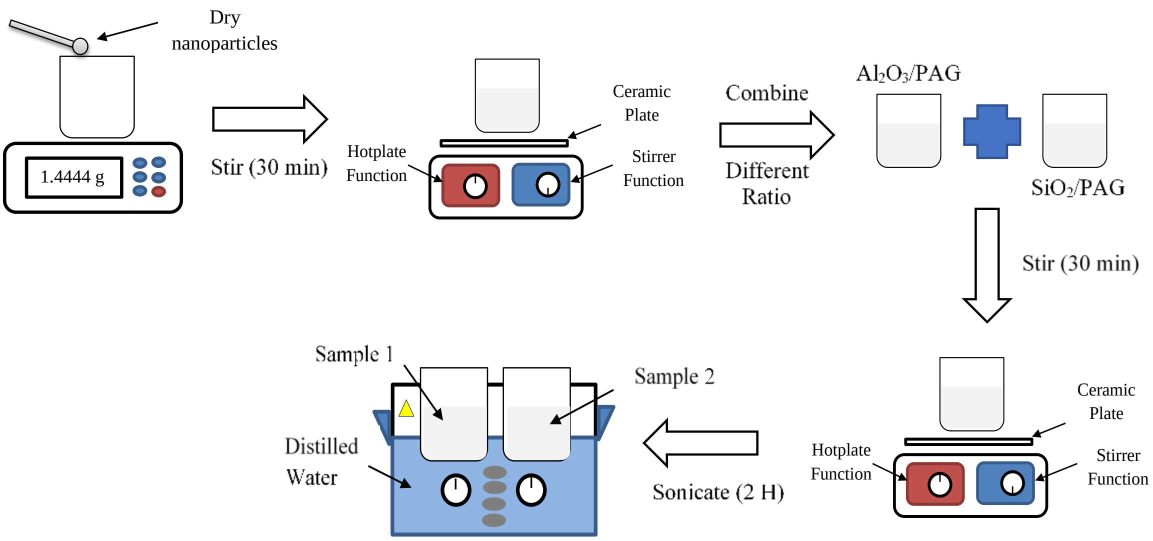

Figure 3. Schematic Diagram of Composite Nanolubricants Preparation

process. The composite nanolubricants were found to have the best stability after 2 hours of sonication. This ideal condition was used in the preparation of all nanolubricant samples. The absolute zeta of the composite nanolubricants of Al_2O_3-SiO_2/PAG ranged to 61.1 mV, indicating an excellent stability. The results of a prior investigation confirmed the duration of the sonication time and the composite nanolubricants stability [35], [50], [51], [70]-[72].

2.2. *Design of Experiments with Taguchi's Method*

The Taguchi method was used to determine the optimum composition ratio to be used for AAC systems that utilized Al_2O_3-SiO_2/PAG nanolubricants. The Taguchi method was chosen due to its efficient and systematic way of optimizing designs for performance, quality, and cost. Besides that, the composition ratio of composite nanolubricants is considered as a discrete variable. The Taguchi method can simultaneously optimize continuous as well as discrete variables. Experiments are performed to find the working levels of each parameter. The five levels observed in the experiments are shown in **Table 3**. The compressor speed, initial refrigerant charges and composition ratios of composite nanolubricants have been selected as operating conditions of the experiments. The highest value of COP and the lowest value of compressor work are considered for performance indicators of the AAC system. The AAC system parameters are denoted as A representing composition ratios of composite nanolubricants, B representing compressor speed and C representing speed initial refrigerant charge.

Since three parameters with five levels are evaluated in the study, the total number of experiments done is 5^3 = 125 if each possible combination is considered by the full factorial design. However, the number of experiments of a three-factor problem with five levels can reduce with the Taguchi method. The number of tests is reduced from 125 to 25 (5^6). Therefore, the L_{25} (5^6) as shown in **Table 4** has been selected to determine the optimum operating parameters of the AAC system. Efficient and systematic ways of design optimization for performance, quality and cost is provided by the Taguchi method due to its approaches in determining the best output performances of various parameters [30]. Results from the experiment conducted based on Taguchi's ORs are collected and are shown in **Table 5**. In this method, every level for all design parameters or factors is equally considered even though only a fraction of the design experiment is conducted. This is because evaluation of the factors can be independent of each other at a lower computational cost. Then, the model results and mean S/N ratios are analysed by ANOVA analysis.

Table 3. Levels and Operating Parameters

Parameters/ Conditions	Units	Symbol	Levels				
			1	2	3	4	5
A – Composition Ratio	%	*A*	20:80	40:60	50:50	60:40	80:20
B – Speed	rpm	*B*	900	1200	1500	1800	2100
C – Refrigerant Charge Mass	g	*C*	95	110	125	140	155

Table 4. Full Factorial Design With Orthogonal Array of Taguchi L_{25} (5^6)

A – Composition Ratio (%)	*B* – Speed (rpm)	*C* – Refrigerants Charge Mass(g)
20:80	900	95
20:80	1200	110
20:80	1500	125
20:80	1800	140
20:80	2100	155
40:60	900	110
40:60	1200	125
40:60	1500	140
40:60	1800	155
40:60	2100	95
50:50	900	125
50:50	1200	140
50:50	1500	155
50:50	1800	95
50:50	2100	110
60:40	900	140
60:40	1200	155
60:40	1500	95
60:40	1800	110
60:40	2100	125
80:20	900	155
80:20	1200	95
80:20	1500	110
80:20	1800	125
80:20	2100	140

Table 5. Full Factorial Design With Results From Experiment

A – Composition Ratio (%)	*B* – Speed (rpm)	*C* – Refrigerants Charge Mass (g)	COP	W_{in} (kJ/kg)
20:80	900	95	7.07	27.20
20:80	1200	110	5.97	31.80
20:80	1500	125	5.68	32.30
20:80	1800	140	5.43	32.80
20:80	2100	155	5.34	31.50
40:60	900	110	7.47	25.10
40:60	1200	125	6.23	29.50
40:60	1500	140	5.73	31.50
40:60	1800	155	5.16	34.60
40:60	2100	95	4.27	44.00
50:50	900	125	7.35	25.60
50:50	1200	140	6.12	30.30
50:50	1500	155	5.37	34.10
50:50	1800	95	4.56	41.50
50:50	2100	110	4.08	44.90
60:40	900	140	8.32	21.70
60:40	1200	155	7.16	24.00
60:40	1500	95	5.69	33.10
60:40	1800	110	4.87	37.30
60:40	2100	125	4.58	38.50
80:20	900	155	8.27	21.50
80:20	1200	95	5.73	33.30
80:20	1500	110	5.12	36.20
80:20	1800	125	4.68	38.80
80:20	2100	140	4.38	40.10

ANOVA is a statistical method used in the design of the experiment to assess the individual interactions of all control factors. Additionally, ANOVA is conducted to determine the effect or sensitivity of each design parameter and the contribution ratios of each parameter to the overall response. In this approach, ANOVA is also used to evaluate the optimal combination of design parameters and the interaction effects between design parameters. In this study, ANOVA was used to analyse the effects of compressor speed, initial refrigerant charge, and composition ratios. This analysis was carried out with 5% significance level and 95% confidence level. The significance of control factors in ANOVA is determined by comparing the F values for each control factor. F values are determined from the ratios of variation between sample means and variation within the samples. Contribution rate indicates the degree of influence on the process performance of each parameter. Percent contribution to the total sum of square can be used to evaluate the importance of a change in the process parameter on these quality characteristics.

3. Results and Discussion

3.1. *Analysis of Signal-to-Noise (S/N) Ratios*

COP and compressor work (W_{in}) were measured via the experimental design for each combination of the control factors by using the Taguchi method. Optimization of the measured control factors was provided by S/N ratios which was important for improvement of AAC system performance. Mean S/N ratios at each level are plotted in **Figure 4** and **Figure 5** for COP and W_{in}, respectively, for better illustration on how the mean S/N ratios changes with each level. The main effect plots are used to determine the optimal design conditions for AAC system performance. The mean S/N ratio analysis on COP performance of AAC system is shown in **Figure 4**. From the figure, all three factors are observed to have a certain influence on the S/N ratios. The 'larger the better' is selected because maximum COP performance is the objective function. For the ratios, the effects decreased up to 50:50 ratios before increasing up to 60:40 ratios and decreasing again at 80:20 ratios. So, the optimum level is level 4 of 60:40 composition ratios of Al_2O_3-SiO_2 nanolubricants. Meanwhile, the effect decreased with the increase of compressor speed up to 2100 rpm. Therefore, the optimum speed is at level 1 of 900 rpm. The refrigerant charge effects increased with the increase of initial refrigerant charge of up to 155 g. Thus, the optimum initial refrigerant charge is at level 5 of 155 g. Overall, composition ratio = 60:40 (A^4), compressor speed = 900 rpm (B^1) and refrigerant charge =155 g (C^5) are determined as the design parameter optimum values for maximum COP.

The mean S/N ratios analysis on compressor work performance of AAC system is shown in Table 5. All three factors are observed to have a certain influence on the S/N ratio. The 'smaller the better' is selected because minimum compressor work is the objective function. The composition ratio effects decreased up to 50:50 ratio before increasing up to 60:40 ratio and decreasing again at 80:20 ratio. Meanwhile, the compressor work effect decreased with the increase of speed for up to 2100 rpm. The refrigerant charge effect increased with the increase of initial refrigerant charge up to 155g. Therefore, the optimum initial refrigerant charge is at level 5 of 155 g. Collectively, composition ratio = 60:40 (A^4), compressor speed = 900 rpm (B^1) and refrigerant charge = 155g (C^5) are determined as design parameter optimum values for minimum values of compressor work.

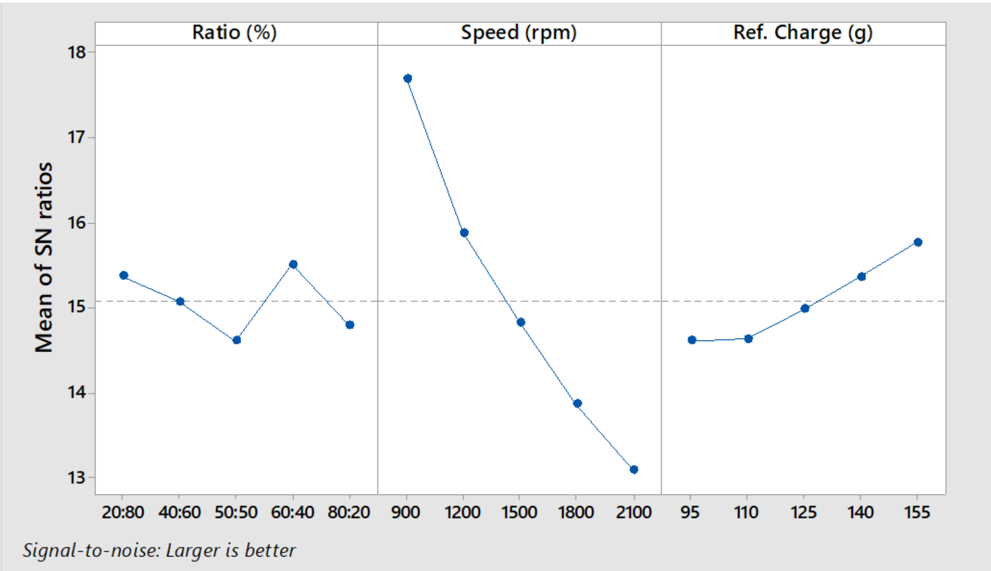

Figure 4. Mean S/N Ratio Analysis For COP

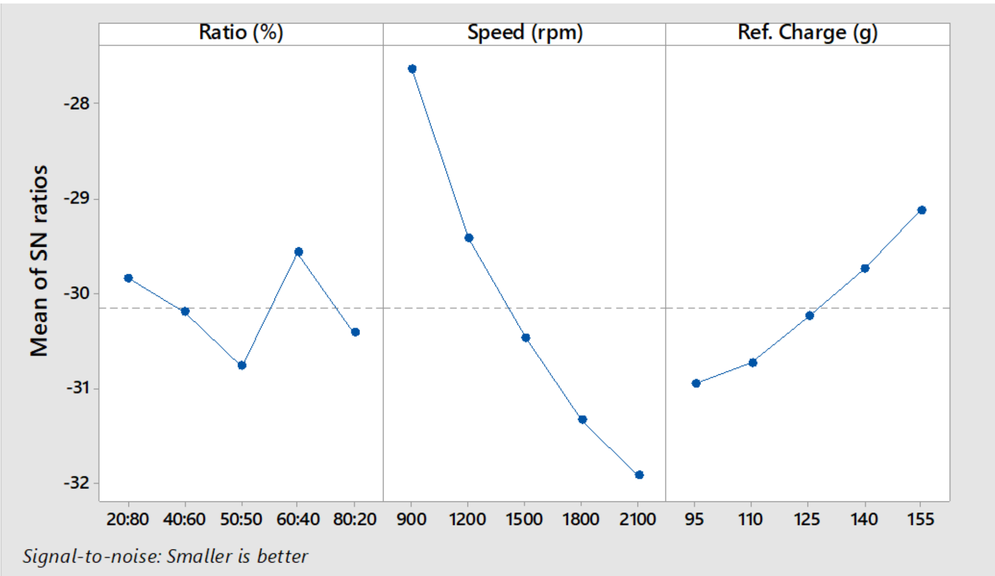

Figure 5. Mean S/N Ratio Analysis For Compressor Work, W_{in}

Table 6 and Table 7 show the results of S/N ratios at different factor levels for COP and W_{in}. The highest S/N ratio indicates the best optimized level for each control factor. The levels and S/N ratios for the factors giving the best AAC performance for COP are specified as factor *A* (Level 4, S/N = 15.51), factor *B* (Level 1, S/N = 17.71) and factor *C* (Level 5, S/N = 15.77). In other words, an optimum AAC performance can be obtained with a 60:40 (A^4) composition ratio of composite nanolubricants at motor speed (B^1) of 900 rpm and at initial refrigerant charge (C^5) of 155 g. For compressor work, the levels and S/N ratios for the factors giving the best AAC performance are factor *A* (Level 4, S/N = -29.57), factor *B* (Level 1, S/N = -27.65) and factor *C* (Level 5, S/N = -29.13). An optimum AAC performance for compressor work can be obtained with a 60:40 (A^4) composition ratio of composite nanolubricants at induction motor speed (B1) of 900 rpm and at initial refrigerant charge (C^5) of 155 g. An optimum AAC performance for compressor work can be obtained with a 60:40 (A^4) composite ratio of composite nanolubricants at induction motor speed (B^1) of 900 rpm and at initial refrigerant charge (C5) of 155 g. According to the results, the most optimal AAC performance can be concluded at $A^4B^1C^5$ levels effectively for both COP and compressor work.

3.2. *ANOVA Analysis*

The ANOVA results for the COP and W_{in} are shown in Table 8 and Table 9, respectively. The effect rates of the AAC system parameters with a low error rate are given in Figure 6. The percent contributions of the parameters *A*, *B* and *C* factors for COP are found to be 3.86%, 87.63% and 6.65%, respectively. Thus, the most important factor affecting the COP is motor speed (factor *B*, 87.63%). According to the ANOVA results, the percent contributions of the *A*, *B* and *C* factors on compressor work are found to be 6.39%, 75.89% and 14.85%, respectively. This indicates that the most effective factor for compressor work is also the motor speed (factor *B*, 75.89%). The percent of error for all factors are considerably low at 1.86% and 2.87% for COP and compressor work, respectively.

Table 6. Response Table For COP

Levels	AAC System Parameters		
	***A* (%)**	***B* (rpm)**	***C* (g)**
Level 1	15.37	17.71	14.61
Level 2	15.07	15.88	14.63
Level 3	14.61	14.83	14.98
Level 4	15.51	13.86	15.36
Level 5	14.79	13.09	15.77
Delta	0.90	4.62	1.16
Rank	3	1	2

Table 7. Response Table for Compressor Work (W_{in})

Levels	AAC System Parameters		
	***A* (%)**	***B* (rpm)**	***C* (g)**
Level 1	-29.84	-27.65	-30.95
Level 2	-30.20	-29.43	-30.74
Level 3	-30.77	-30.48	-30.25
Level 4	-29.57	-31.33	-29.74
Level 5	-30.42	-31.93	-29.13
Delta	0.63	3.16	0.80
Rank	3	1	2

Table 8. ANOVA Results for COP

Parameters	DF	SS	MS	F-Value	P-Value
A (%)	4	0.03818	0.009546	6.23	0.006
B (rpm)	4	0.86582	0.216456	141.34	0
C (g)	4	0.06568	0.016419	10.72	0.001
Error	12	0.01838	0.001531		
Total	24	0.98806			

If the p-value is less than 0.05%, and the corresponding term is significant

Table 9. ANOVA Results for Compressor Work

Parameters	DF	SS	MS	F-Value	P-Value
A (%)	4	0.4981	0.12454	6.69	0.005
B (rpm)	4	5.9139	1.47848	79.42	0
C (g)	4	1.1571	0.28927	15.54	0
Error	12	0.2234	0.01862		
Total	24	7.7926			

If the p-value is less than 0.05%, and the corresponding term is significant.

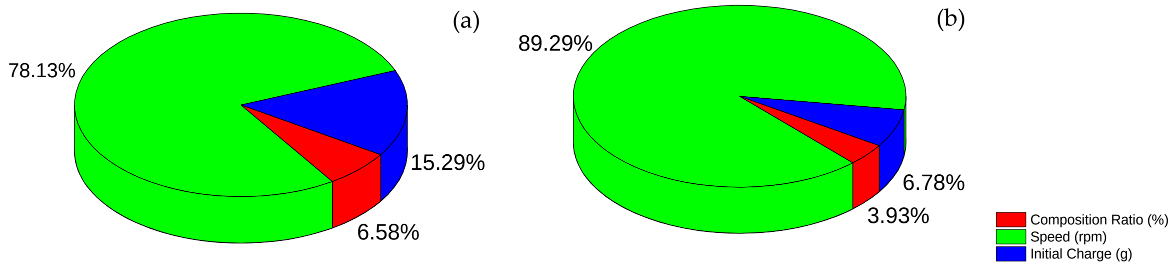

Figure 6. Rate Contribution of AAC System Parameters (a) COP (b) Compressor Work

Table 10 shows the model summary for optimization analysis. The calculated coefficient of determination, (R^2) indicates the quality of fit of the obtained model and describes that the amount of variation observed in yield is explained by the input factors. For COP, R^2 = 97.87% indicates that the model can predict the response with high accuracy. Meanwhile for compressor work and cooling capacity, the R^2 are 96.72% and 95.39%, respectively. For multiple linear regression analysis, R^2 values should be between 0.8 and 1 [25]. All results obtained in this study are in good agreement with the regression model (R^2>0.80). The "Pred R-Squared" of 0.9321 for COP is in reasonable agreement with the "Adj R-Squared" of 0.9563. Meanwhile, the "Pred R-Squared" of 0.9045 for compressor work is in reasonable agreement with the "Adj R-Squared" of 0.9386. The standard deviation of errors in the modelling, S_{COP} = 0.007 and $S_{compressor\ work}$ = 1.597. The optimum values of factors and their levels for the AAC system in the study are summarised in **Table 11**.

Regression analysis is used to examine the relationship between a dependent variable with one or more independent variables and can be in the modelling and analysing variables [52]. The operating parameter mathematical models obtained from the regression analysis can predict the performance of AAC systems in terms of COP and compressor work. The regression equation for COP and W_{in} are given by **Eqs. 2** and **3**. The *x* and *y* value are given in **Table 12**.

$$\text{COP} = \frac{1}{x + 0.000075\ B - 0.000414\ C} \tag{2}$$

$$W_{in}\left(\text{kJ kg}^{-1}\right) = y + 0.012793\ B - 0.1143\ C \tag{3}$$

3.3. Prediction and Validation at Optimized Parameters

A confirmation experiment of the control factors [53] suggested by the Taguchi optimization technique is important for validation of the optimized conditions [54]. Five trial runs were carried at optimum levels ($A^4B^1C^5$) to validate and evaluate the reliability of the developed regression model against the experimental results as shown in **Table 13**. The predicted and experimental values are very close to one another. Error values should be below 20% for reliable statistical analysis [52], [55]. **Eq. 4** was used to calculate the error rates between the experimental and Taguchi findings [56]. The calculated error values were noted to be less than 10% for all runs and within acceptable limits. Thus, the validation results were found to be in good agreement with the present experimental data, reflecting a successful optimization.

$$\%\ \text{errors} = \frac{\text{Experimental Results - Optimized Results}}{\text{Experimental Results}} \tag{4}$$

Table 10. Model summary for AAC systems

Responses	S	R-sq	R-sq (adj)	R-sq (pred)
COP	0.007	0.9672	0.9563	0.9321
Compressor Work (kJ kg^{-1})	1.597	0.9539	0.9386	0.9045

Table 11. Optimum Values of Factors and Their Levels

Parameters	Optimum Value
A – Composition Rasio (%)	60:40
B – Speed (rpm)	900
C – Refrigerant Charge Mass (g)	155

Table 12. *x* and *y* value for regression model

Composition Ratio (%)	*x*	*y*
20:80	0.1099	26.21
40:60	0.1181	28.03
50:50	0.1287	30.37
60:40	0.1105	26.01
80:20	0.1251	29.07

Table 13. Validation Experiment Results Based On Taguchi Optimal Parameter

No	Optimal AAC system parameters					
	Compressor Work, W_{in} (kJ kg^{-1})			COP		
	Optimized value	Experimental value	Error (%)	Optimized value	Experimental value	Error (%)
1		22.20	8.86		8.23	6.74
2		22.00	9.85		8.31	5.72
3	$A^4B^1C^5$	22.40	7.89	$A^4B^1C^5$	8.17	7.53
4		22.10	9.35		8.28	6.10
5		22.00	9.85		8.30	5.84

4. Conclusions

The operating parameters considered were mixture composition ratios, speed and initial refrigerant charge each at five levels. The optimal conditions of these parameters were obtained using the S/N ratio analysis of Taguchi method (L_{25}) and ANOVA is carried out for determining the influence of given input parameters from a series of experimental results by Taguchi method. Taguchi design of experiment can be very efficiently used in the optimization of operating parameters in AAC system. Then, the optimum COP and compressor work were calculated by Regression equation. An optimum AAC performance can be obtained with a 60:40 (A^4) composition ratio of composite nanolubricants, at motor speed (B^1) of 900 rpm and at initial refrigerant charge (C^5) of 155 g. The motor speed is the most dominant contributing factor for optimum COP and compressor work with 87.63% and 75.89% respectively. The validation test runs were carried out to validate predicted results against the experimental results. The developed model shows that the predicted results are in excellent agreement with the experimental results with error less than 10%. Therefore, it was recommended to use Al_2O_3-SiO_2/PAG composite nanolubricants with operating conditions of $A^4B^1C^5$ for optimum performance in the AAC system.

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Author's Declaration

Authors' contributions and responsibilities

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by N.N.M. Zawawi. The first draft of the manuscript was written by N.N.M. Zawawi and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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